PERSPECTIVES IN SCIENCE AND TECHNOLOGY

VOL. I

SCIENCE ADVISORY COUNCIL TO THE PRIME MINISTER
DEPARTMENT OF SCIENCE & TECHNOLOGY
GOVERNMENT OF INDIA

The Science Advisory Council to the Prime Minister was constituted in 1986 as an Apex Body to advise the Prime Minister on major issues related to science and technology in the country, and also to prepare a perspective science and technology plan for 2001 A.D. The Council was also expected to examine certain matters connected with scientific departments, priorities in research, technology missions etc. During its four-year term the Council studied many issues of direct relevance to science and technology in the country and also several topics with bearing on the socio-economic sectors. These studies of the Council have been disseminated among the scientific community in the form of individual reports. Although some of these reports may not be comprehensive, they were certainly indicative of the vital issues involved and action required in the relevant areas. The Council also examined a few important topics of futuristic value as well.

This special publication contains all the important reports prepared under the auspices of the Science Advisory Council to the Prime Minister. This publication is likely to be of archival value to the science community as well as to policy makers and administrators.

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Perspectives in Science & Technology

Technical Reports

by

The Science Advisory Council
To The Prime Minister

Vol. I

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Wellcome Centre for Medical Science

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Department of Science & Technology
Government of India

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Foreword

The Science Advisory Council to the Prime Minister was constituted in 1986 as an apex body to advise the Prime Minister on major issues related to science and technology in the country, and also to prepare a perspective science and technology plan for 2001 A.D. The Council was also expected to examine certain matters concerned with the scientific departments, priorities in research and development, technology missions and so on.

The Council has now been functioning for nearly four years. It has studied many issues of direct relevance to science and technology in the country and also several topics with a bearing on the socio-economic sectors. In carrying out such studies, working groups were set up by the Council and the recommendations and reports of such groups were later discussed by the Council, before finalising the reports. Many of these reports have been disseminated among the scientific community. Although some of these reports may not be comprehensive, they are certainly indicative of the vital issues involved and the action required in the relevant areas. Some of the reports commissioned by the Council related to important topics of futuristic value as well, but it has not, however, been possible to cover all the areas that one would have liked to.

It is indeed gratifying that it has been possible to bring out a special publication containing all the important reports prepared under the auspices of the Science Advisory Council to the Prime Minister. We believe that this publication is likely to be of archival value to the scientific community as well as to policy makers and administrators. We would have very much liked this volume to contain many other vital topics of interest but, unfortunately, it has not been possible to bring out these reports in time for publication.

I would like to acknowledge the support and encouragement of the Prime Minister in the work of the Council. I wish to record the contributions made by the members of the Council whose camaraderie and dedication made the work of the Council a matter of pleasure. I am most thankful to the chairmen and members of the various working groups who produced the reports for the Science Advisory Council. I would like to acknowledge the support of Dr P J Lavakare and the members of the Secretariat of the Council in bringing out the reports. I am also thankful to Dr Srinivas Bhogle of the National Aeronautical Laboratory for his assistance and advice in bringing out this publication.

C N R Rao
Chairman
Science Advisory Council
to the Prime Minister

November 1989.

Editor's Note

This compilation has been divided into two volumes.

The first volume contains (a) the approach paper, prepared by the SAC-PM, on a perspective science and technology plan for the year 2001, and (b) seven other reports on the frontier areas of research and development.

The second volume contains nine more reports broadly classified under the category of 'areas of socio-economic relevance'.

Since the reports have been prepared by different expert teams (please see annexure-2 for the composition of these teams), the style of writing and presentation is not always uniform. Some of these reports have also appeared as individual technical reports of the SAC-PM (the approach paper with the red cover has already been widely circulated), but there are others which are being published for the first time.

An Approach to a Perspective Plan for 2001 AD: Role of Science and Technology

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We believe that if our resources, the needs of our people, the S&T expertise and our managerial and administrative talents are all carefully interwoven, we will start producing a tapestry of change which will start meeting the needs of larger and larger sections of our people in the coming years.

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1

An Approach to a Perspective Plan for 2001 AD: Role of Science and Technology

Preamble

In July 1988, the Science Advisory Council to the Prime Minister circulated a paper entitled "Approach to a Perspective Plan for 2001 AD: Role of Science & Technology" emphasising the need to incorporate science and technology in planning for development (see Appendix-1). This document was discussed with the Planning Commission, and with a wide cross-section of scientists and other professionals representing a variety of interests and disciplines, at discussion meetings held in Bangalore, Bombay, Calcutta and Delhi (Appendix-2). The Council also had considerable correspondence regarding the document with many others. This interaction has been of great benefit to the Council, and has led to the preparation of this document, whose main objective is to outline in somewhat greater detail specific recommendations for action in the light of an underlying philosophy of perspective planning. It is hoped that the present document, together with the Approach Paper, adequately describes the strategy for development being proposed by the Council, and may be useful in formulating the forthcoming Eighth Plan as well as a more detailed perspective plan for the country. We will be happy if Government agencies, ministries and individual institutions find this document of some use in preparing their own perspective plans.

The Council has derived great satisfaction from the task of preparing this document, and would like to acknowledge the help that it has received from a large number of friends and colleagues who have responded to our invitation and made valuable comments and suggestions.

It is the belief of the Science Advisory Council that a time has come in our nation's life to plan for striking advances in improving the quality of life of its citizens. But perhaps it needs to be stressed that such advances will be possible in the near future only if we can control our population growth: population planning therefore holds the key, in our view, to the achievement of such goals. ■

1 Introduction

- The importance of science and technology to economic development was recognised in the country quite early, chiefly because of Pandit Jawaharlal Nehru's strong commitment to utilising S&T in all our national efforts. There has thus been some form of a scientific advisory committee to the Central Government or to the Cabinet from the early years of our Independence. The first major effort in preparing detailed S&T plans for various sectors was made by the National Committee on Science and Technology (NCST) in the early 1970s. NCST underscored the importance of integrating S&T into our developmental plans, but in spite of the Committee's commendable efforts, S&T inputs to economic planning have continued to be marginal. The erstwhile Science Advisory Committee to the Cabinet (SACC) and the S&T wing of the Planning Commission have, in recent years, made efforts in the same direction, but the integration needs to be improved.

- One of the tasks of the Science Advisory Council to the Prime Minister has been to define the role of S&T in perspective planning for 2001 AD. The Council realises the difficulty in fulfilling such a task in the absence of a long-term national perspective plan with well-quantified targets. For example, it may be useful to set a target for per-capita income by the turn of the century. The commitment of planners to such precise targets would make it somewhat easier to come out with an S&T plan. Even in the absence of such targets, however, an effort to enunciate the philosophy of perspective planning where S&T is fully integrated should be an exercise of great value.

- Any approach to planning must ensure that development goes hand-in-hand with social justice. The Science Advisory Council is conscious that problems such as population planning and improvement of health are largely societal issues and cannot be solved by S&T alone. Even where there is a significant S&T component in such efforts, we need the commitment and participation of the community as a whole, of social scientists, voluntary agencies (especially women's movements) and the government to achieve sustainable development.

We shall first examine some of the issues of relevance to perspective planning before listing the major recommendations for action.

2 Some Important Issues of Concern

In the Approach Paper (Appendix-1), it has been emphasised that the role of S&T in perspective planning needs to be examined in two parts: (a) use of S&T in planning, and (b) planning for S&T.

Against this background, several basic issues were considered, the most important ones being

- control of population,
- need for increased food production,
- protection of the environment,
- improving human health,
- control of hyper-urbanisation, and
- reducing unemployment.

Other crucial sectors identified were *energy, communications, transport, manufacturing, materials, instrumentation and higher education.*

- The Approach Paper recognised *conservation* to be of paramount importance in planning for development. The word conservation as used here includes the efficient use of our resources, whether they are human or material, or relate to energy, and the effective use of what are commonly thought to be 'wastes' in the generation of wealth. It is widely recognised, for example, that even a small saving in the power loss in transmission would go a long way in helping our resource position. Our plans could and should get more out of existing assets.

- A high percentage of our people are illiterate and below the poverty line without access to drinking water, proper sanitation or adequate shelter. The absolute number of such people is continually increasing. These people are yet to benefit from modern science and technology. Greater attention is needed to social services, and our policy for S&T must reflect the broader issues confronting society and become an integral part of national policies for development. We cannot forget that the primary goals of our nation have to be to provide the basic needs for the common man and to improve the quality of his life.

We have to examine all feasible alternatives and set the right priorities in our programmes related to shelter, energy, transportation and health. For example, while it is important to work out our strategies for commercial sources of energy, we must realise that non-conventional sources (biogas, smokeless chulas, etc.) will play a key role at least till commercial forms of energy become widely available throughout the country. Similarly, while devising medical or health care programmes, we have to ensure that the right balance is maintained between indigenous and western systems of medicine, as the former are likely to make a valuable contribution to the general well-being of the population; in this context, we may have lessons to learn from some of our neighbouring countries. Educating multipurpose workers, technicians and nurses in our villages may be more important than training more doctors. While planning for housing for our large population, we must recognise the possibility of achieving significant short-term results in shelter in rural areas by the application of S&T for the improvement of traditional materials and methods of construction.

- While we have to make sure that appropriate S&T inputs go into solving problems related to the essential needs of the common man, we have at the same time to work out plans which will make the country economically stronger. We see no real conflict in planning for a quantum leap in industrial growth and at the same time making all-out efforts in solving the pressing problems of our society. One of the main recommendations that we make is that the industrial sector should fully make use of the available R&D capability and become export-oriented so that it can earn more resources for the country. While we have to develop a good home market, it is as important to see that we have a good export market if we have to acquire the resources necessary to achieve our ambitious development goals. Export-oriented industries would also raise employment levels and enhance the quality of workmanship as well as of products.

- It must be recognised that national planning in the last few decades has provided by and large a balanced programme with a mix of both command and competitive economies. One of the important themes in these planning efforts has been self-reliance. The term ''self-reliance'' does not of course mean total technological self-sufficiency. Today we have to look beyond self-reliance, because the industrial scenario demands that we should be internationally competitive or significant at least in a few selected areas. This cannot be attained without the support provided by powerful indigenous capabilities in many areas of S&T. Indigenous capability is a national resource, but should in particular be directed towards those industries in which we can develop our national advantages into international competitiveness, importing, where necessary, technologies that will support this effort. (We here exclude those others where national security may demand total self-reliance, or even self-sufficiency.) But even to buy advanced technology intelligently, we must have done some work on it. The ultimate goal is development, which has to be interpreted in a broad sense and pursued with pragmatism in our planning and in all other efforts. A carefully worked-out policy is therefore of paramount importance to decide on the criteria for the right mix in our technological efforts.

- Unlike mission-oriented and strategic areas such as atomic energy and space that have set well-defined targets and formulated their needs for research and development, we are yet to utilise adequately our potential for S&T development in key economic sectors. These sectors are under socio-economic ministries many of which have scientific advisory committees, but this mechanism has not been uniformly effective. Thus S&T is yet to make a dent in many important sectors involving heavy investments. For example, there is hardly any change in our construction technology over the years, even though most of our development budget goes into construction and we are even short of conventional building materials. We will also have to find ways of determining the *inter-se* priorities amongst the various sectors. S&T should be involved in all major investment decisions, in both public and private sectors, and be properly used as a tool for national development.

- The national scenario in science and technology education is not encouraging and steps need to be taken to upgrade the infrastructure of institutions and promote excellence.

- Another lacuna has to do with the absence of a working machinery for incorporating S&T into our planning at the state, district and village levels. Unless planning is at the grassroot level, the results of our plans will not reach all sections of the country. Voluntary agencies and state S&T councils have much to contribute in this direction.

- As already pointed out, a matter of the greatest concern is the staggering growth of population. Whatever we accomplish in industrial growth or in food production may be of little consequence in improving the quality of life for the average citizen if the rate of growth of population does not subside.

- An equally discomforting factor is that the mechanisms available today for implementing our plans are not good enough. Unless bureaucratic impediments, procedural delays and outdated management strategies are eliminated, no plan, however good, will have a significant effect on our economy. If we are serious about improving the quality of life of the common man and transforming our country into an economic power, greater effort should be made by government and all concerned, in finding better mechanisms and procedures for the implementation of our development plans. We have suggested a few modalities, but they alone may not suffice. What may be necessary is a major restructuring and overhauling of the administrative and management machinery dealing with S&T.

3 Recommendations for Action

3.1 Population

The problem of population has to be tackled on the mission mode (see the Approach Paper in Appendix-1 for details). With appropriate planning, we must limit the country's population to no more than 970 million by 2001 AD. Should we fail to act in time, we may well have to provide extra resources for an additional 55 million by that year. The moot question is ''When will India's population growth start decelerating?''

A former State Director of Population Control has remarked that most states report incorrect demographic data in order to ensure that the Centre allocates them larger grants annually, as the overall fund allocation to states is dependent in part on their population. The undesirable effect of this policy is confirmed by the mid-term review of the Seventh Five Year Plan. Clearly grants to states (and other related economic policies) must act as an incentive to population control.

We believe that one of the most effective methods of population control is the widespread education of women. While the population control mission is chiefly societal, S&T inputs are important in

- development of fertility regulation techniques,
- offering medical knowhow,
- harnessing communications technology and contributing to informed health education, and
- providing adequate managerial skills.

Voluntary agencies, mofussil colleges and district level S&T setups can play a crucial role in this mission.

In order to strike a balance of population growth with opportunities by developmental plans, action has to be directed towards providing better opportunities for women and guaranteeing security for the old. We advocate schemes by which the resources saved for the nation by those who plan their families can be passed on in part to them, through incentives in the form of health care and education for the children, and of social security for the parents.

3.2 Food

Production of foodgrain has to be an important mission if we are to achieve the target set in the Approach Paper of approximately 300 million tonnes per annum by the end of the century. Meeting the requirements for food can only be accomplished through a series of measures such as

- optimisation of areas suited for intensive agriculture,
- improvement in rainfall forecasting,
- better water management,
- conservation of soil and ensuring supplementation of nutrients after intensive agriculture,
- upgradation of the genetic productive potential of major crops,
- improvement in yields of fruits and vegetables,
- improvements in animal husbandry,
- improvements in aquaculture,
- exploration of ocean beds for marine food reservoirs,
- conservation of food including storage and packaging,
- improvements in the production of fertilisers with new S&T inputs,
- education of farmers on new S&T inputs to agriculture, and
- intensive reforestation to prevent soil erosion and flooding.

3.3 Industry

- Our industry has to become internationally competitive at least in select areas if we are to significantly enhance the generation of wealth in the nation. To achieve this objective, there is an urgent need to improve the quality and efficiency of production and for value-addition on all products, and to recognise the large multiplication factor that can be provided by innovative application of S&T. We recommend a position of greater authority to R&D personnel in the board rooms of both public and private sectors.

- We are impressed by the vigour and performance of relatively small-scale industry in low- as well as in certain high-technology areas, and in its ability to utilise indigenous R&D for the creation of wealth. We urge that national S&T agencies devote a greater part of their resources and efforts to promote this sector, which can provide the foundation for the growth of a healthy and self-confident S&T base for the country.

- Export promotion should be one of the main objectives of our country. We recommend the establishment of exclusive export zones in selected areas to facilitate manufacture of products requiring high grade technology for export. The electronics industry has to be given special attention in the next few years if India has to enter the world market as a supplier of quality products.

- The DGTD should be replaced by a Directorate for Industrial R&D in order to catalyse the creation of an Industrial R&D infrastructure.

3.4 Infrastructure in S&T

More effective coordination of current and future S&T activities in the country is long overdue. The following organisational structure provides a means of ensuring more direct S&T inputs into planning.

- The Approach Paper (Appendix-1) proposed a National Science & Technology Commission (NSTC) to oversee the role of S&T in planning and to decide priorities within the various sectors. In discussions on the Approach Paper, understandable fears have been expressed that such a Commission might lead to a proliferation of bureaucracy. We therefore wish to reemphasise that NSTC is not envisaged as a parallel organisation to the Planning Commission, but rather as a tool that should strengthen the S&T inputs to the Planning Commission. Most importantly, it will coordinate collaboration amongst different science agencies in the country, and help to bring together the S&T resources in the country to bear upon the planning process. We do not see any other way in which planning in India may utilise S&T to fulfill our social priorities and meet targets in key areas more effectively than in the past. In turn, NSTC will utilise fully the analyses and forecasts that the newly created Technology Information, Forecasting and Assessment Council (TIFAC) will provide.

- Economic ministries should effectively utilise their Science & Technology Advisory Committees, and should in addition be assisted by an Adviser (at least at the Additional Secretary level), with mandatory requirement of clearance of projects from the S&T angle.

- The state level councils of S&T need to be activated to bring about greater involvement of states in applying S&T to solve their developmental problems. In the first stage, it is proposed that strong linkages be forged between the Planning Commission and the NSTC on the one hand and the State Councils on the other, and eventually, between the State Councils and the districts or blocks within the state. We further see no reason why such State Councils should not play a more active role in promoting competitive high technology efforts, especially in the small-scale sector.

- In order to involve the community as a whole to play a role in identifying issues and suggesting alternative strategies for development, a new institutional structure would be necessary. An autonomous institution (employing a corporate R&D approach) involving a network of local units may be necessary to focus on and apply methods of modern S&T to solve real issues of society. Details of such a structure can be worked out by SAC to PM with the Planning Commission and other concerned agencies.

As an immediate step, we recommend the creation of district level centres/committees of S&T to discuss and implement S&T inputs in local projects.

- Areas such as mineral development, civil aviation, instrumentation, telecommunications and materials technology can be effectively served by the formation of specific boards or corporations as appropriate (see Appendix-1).

The creation of numerous new structures always poses the risk of non-productive investment, which can only be avoided by placing concrete and specific goals before them. This is of course a formidable challenge, but one that must be faced if we wish to make S&T successful in planning and implementation.

3.5 Human Resources

Next to population control, the most critical issue facing us now, and one likely to continue doing so in the future, is the generation of *employment,* especially in rural areas. Generating employment which is fulfilling to the individual and is in consonance with our economic and developmental needs provides a social opportunity which must be carefully exploited. Industries generating employment (food-processing, low-cost manufacture of building materials etc.) should be promoted. Employment, particularly of women, requires to be dealt with as a subject of critical importance in its own right. We believe that women are the key to tackle effectively and imaginatively such questions as population growth, health and wide-spread education.

The application of S&T in a more intensive manner automatically generates a need for trained and skilled manpower planning. Training of such manpower is the legitimate function of universities, but the state of our universities has significantly deteriorated, with a proliferation of colleges with inferior facilities; some measures to reverse this trend are as follows.

- Initiate a programme of providing excellence in science education by establishing consortia of universities that can work in collaboration with higher institutions of learning, such as TIFR, IISc, the IITs etc., utilising their superior resources, both human and material.

- Initiate immediately postgraduate programmes in certain special areas of engineering and technology (such as mathematical modelling, computer simulation, materials technology, materials processing, polymer technology etc) at some of the national laboratories which may be given the status of deemed universities for running such programmes.

- Establish joint centres (along the lines of the CNRS in France) run by national laboratories and universities together to provide better research and developmental facilities to the university sector.

- Promote centres of excellence in universities around gifted scientists and engineers, individually or in small groups, and provide them with flexibility and a degree of autonomy from the university administration, which is often not sensitive to the needs of research. Even in the higher institutions, the quality of infrastructural support now available leaves much to be desired, and should therefore be improved.

- Create of advanced centres for research to be named after Jawaharlal Nehru to commemorate his birth centenary.

- Grant autonomy to science and engineering colleges with a proven track record.

- Provide large scale funding for improving institutional infrastructure of universities and other educational institutions as well as selected science and engineering colleges

- Introduce innovative ways of training competent manpower for frontline areas of S&T (e.g. short-term training in chosen areas in identified institutions abroad).

- Formulate schemes for the very important task of training various categories of highly skilled technicians, in view of the current acute shortage (the present polytechnic being outdated).

- As human and technological skills are the key to the creation of greater national wealth, take steps to ensure that such skills are commensurately rewarded.

3.6 Conservation

Since conservation and efficiency play a crucial role in fulfilling our cherished goals, important measures need to be taken, some requiring legislation, to see that they pervade all our efforts. Some measures are indicated below.

- Explore alternative fertiliser technologies (e.g. better hydrogen recovery from ammonia plants, controlled release of urea).
- Develop a proper national water policy for conservation, management and harvesting.
- Adopt technologies for storage and conservation of food employing appropriate post-harvest technologies and creating packing and processing industries.
- Develop strategies for conservation of energy supported by appropriate auditing and enforcing machinery.
- Strive to maintain the country's heritage of biological diversity.
- Promote programmes for enhancing the biological productivity of our land.

3.7 Other Important Issues in S&T

The other issues in S&T which need to be kept in view while formulating long-term plans are as follows.

- An autonomous National Science & Engineering Research Board (NSERB) should be created to become the prime focus for funding of basic research (see the Approach Paper in Appendix-1). Multiple funding of R&D should however continue, from agencies oriented to achieving specific technological missions.

- Provision must be made to promote and exploit discoveries and breakthroughs of unanticipated nature, e.g. high temperature superconductivity, which is recognised as something which might affect major technologies of the 21st century. It is gratifying that a special organisation and funding mechanism were established for the purpose in 1987.

- The knowhow and technology priorities of the small scale sector which has an important role to play both in employment generation and export performance should receive special attention.

- In order for the S&T culture to percolate through society, a specific plan must be formulated which provides for two-way communication as opposed to the top-down communication now prevailing.

4 Concluding Remarks

We have listed above certain recommendations related to the use of S&T in planning for development. These recommendations are selective rather than comprehensive, but we believe that they need to be executed if the country wishes rapid economic growth accompanied by an overall improvement in the quality of life by the turn of the century, goals which appear to us to be feasible.

As we make these recommendations, we are conscious that the forces governing such rapid and internationally competitive industrial growth in the next decade will demand R&D for most industries, creating corresponding demands on S&T. This growth in the industrial sector, however, if accompanied by an unabated growth in our population and possibly increasing poverty and unemployment, may lead to social imbalance if we do not take adequate corrective measures. Scientists, engineers, sociologists, economists, industrialists, community workers and political leaders need to get together to examine the issues that our society would have to face by the turn of the century.

It is not unlikely that our development efforts will encounter certain crucial shortfalls, perhaps with respect to highly trained technical manpower and materials apart from possible fiscal limitations. Immediate steps should be taken to see that the competent manpower needed to tackle the problems of tomorrow, and the variety of materials required in various sectors (chemicals, ceramics, chips, structural materials, metals etc.), both become available.

By the turn of the century, it should be possible to see that S&T makes inroads into planning at village, district and state levels. Voluntary agencies and S&T centres operating at these various levels should help in tackling local and regional problems through the application of S&T and ensuring that the S&T efforts required for the purpose of societal transformation find a due place in our planning. Once such efforts bear fruit, we may expect a total change in national attitudes to S&T, and we may hope that a widely prevalent scientific temper amongst a large section of our population will make our society culturally richer and more vital.

Appendix-1

Approach Paper Prepared by SAC-PM

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Synopsis

The remarkable economic development that this country has witnessed in the last 40 years has been governed by a series of Five Year Plans, drawn up after extensive discussion and analysis by the Planning Commission. The Science Advisory Council to the Prime Minister has been charged with the task of suggesting strategies for incorporating science and technology in a perspective plan for the period upto 2001 AD. While attempting to carry out this task, it has become clear to the Council from its discussions with the Planning Commission and the Economic Advisory Council that planning *for* our science and technology is not yet integrated with planning for economic development. Whatever may be the compulsions that have been responsible for this dichotomy in our Plans till now, the Council is convinced that the time has now come for close integration of S&T *into* planning, and indeed that without such integration it is most unlikely that we will achieve the ambitious social and economic goals that the country needs, and is being asked, to set for itself.

The purpose of this approach paper is to indicate, in the light of the above considerations, certain new directions in which we believe it is now essential for us to move. First of all, we consider that plans for S&T must be geared directly towards meeting the basic needs of the population (food, housing, health, employment and education) and modernising our infrastructure in such major service sectors as energy, transport and communications: support for relevant research and development in these sectors has with rare exceptions been inadequate. Secondly, the crucial role that materials technology will play in national development - in areas ranging all the way from housing for the poor to chips for new computers - has to be appreciated and consciously planned for. Thirdly, the revolution being wrought by developments in information technology needs to be harnessed for the national effort - once again in all areas, ranging from health to technology assessment and forecasting. Finally, it is important to ensure that industrial growth goes hand in hand with greater technological capability. We also have to appreciate that there is no real conflict between working towards the primary social goals of the nation and promoting an efficient, internationally competitive industry with a certain export orientation.

In moving in these directions, we should in particular select and stress those areas of science and technology that can help to yield the following outcome by the turn of the century: a targeted deceleration in population growth, a doubled food production from agricultural and other sectors and a substantially larger gross domestic product, health for all and literacy and housing for the vast majority of the population, a comfortable situation nation-wide in the primary service sectors of energy, transport and communications, a reversal in ecological erosion, an increased export market for Indian manufacturers and services, and world leadership in selected areas of science and technology. We state this with the feeling that a time has come in our nation's life when the propensities are right for progressive developments to occur.

We are convinced that to achieve such goals some restructuring of the management system for S&T in planning for economic and social development is essential. In particular, we suggest the establishment of a National Science & Technology Commission, to help in integrating S&T into planning, to identify appropriate technology missions, and to coordinate and whenever necessary to manage collaboration between the different agencies of the Government concerned with technology development, economic planning and financial resources, as well as with private and public sector industry. We also suggest selective efforts in higher education and research and promotion of excellence in a concerted fashion.

This approach paper is not intended to be comprehensive, nor can it replace the massive exercises that the Planning Commission has necessarily to carry out in formulating our Five Year Plans. We have raised several issues that appear crucial to us and suggested certain strategies in an effort to present a philosophy of perspective planning wherein S&T plays a key role. We would feel rewarded if the attention of planners and scientists is drawn to the major new directions that seem to us to be now necessary, and would welcome comments from them on the proposals contained here for the integration of S&T with planning and, as part of this effort, for the measures to be taken for promotion of S&T in general. We also hope that the approach paper will act as a catalyst in the preparation of innovative perspective plans by all the concerned departments, agencies and institutions. ■

1 Prologue

- After 40 years of independence, the process of economic planning through the Five Year Plans has become an accepted mechanism for national development. Any approach to perspective planning for the future has to be necessarily based on our past experience and an objective analysis of our past successes and failures. It is obvious that our approach now requires a sense of urgency and dedication to the concept of "getting things done", in a given time frame, by evolving appropriate and effective implementation mechanisms. We are convinced that the tools of science and technology are ideally suited for such an approach. This paper therefore emphasises the effective use of science and technology in economic planning as well as the importance of planning for science and technology.

- National planning, as conceived by Pandit Jawaharlal Nehru, is the lynchpin of India's economic development. While we can argue as to how much better off we might have been if all the Plan targets had been achieved during the past few decades, it is important to note that the economic gains we have made have not been insignificant. Until recently, there were doubts about India's ability to produce surplus food. Today there are questions about our ability to control our population and eradicate poverty. In the case of food production, the doubts turned out to be challenges which we have successfully met. The principal instrument was planning, while the motive force was the political will to use science and technology as vehicles for development.

- This element of using S&T in planning, highlighted by Mahalanobis and others, when coupled with the intense efforts of Bhabha and Bhatnagar in planning for science and technology, became the essence of Panditji's approach or the "modus operandi" of economic planning for the country. It was Panditji who clearly enunciated these concepts by assigning to science and technology a pivotal role, when he stated in the Scientific Policy Resolution (1958) that:

> "The key to national prosperity, apart from the spirit of the people, lies, in the modern age, in the effective combination of three factors, technology, raw materials and capital, of which the first is perhaps the most important, since the creation and adoption of new scientific techniques can, in fact, make up for a deficiency in natural resources, and reduce the demands on capital."

- The establishment of the Atomic Energy Commission, the modernisation of the Defence research establishment, the initiation of the green revolution, the exploration of oil and natural gas and the entry into the space era are some of the examples of the application of science and technology to the nation's development plans which were adopted by Panditji and subsequently by Smt Indira Gandhi. It was recognised that when critical targets had to be achieved, political will and vision for the application of science and technology had to be interwoven into our planning process. Such a missionary zeal for the application of science and technology has been eloquently defined by Shri Rajiv Gandhi, who, through the identification of priority National Technology Missions, has provided renewed impetus and imparted a sense of urgency to solving some of the crucial problems faced by our society.

- Although S&T has been utilised earlier in the mission mode for achieving certain goals in programmes in Atomic Energy and Space, it did not become an integral part of overall national planning. The national plans were, and continue to be, mostly dependent on economic exercises and allocation of funds derived from it. These allocations include funds for sectors such as Education, Health, Communications, Energy and the varied aspects of Science & Technology. We are convinced that for planning to be more effective and to more accurately reflect our aspirations, there is need for considerable change in the manner in which we use S&T in the total planning process and the way we execute the plans.

- Planning must start by taking into account the needs and aspirations of our people at the grass-root level and build up from there into an integrated and meaningful national plan. The concept of district level planning is therefore very relevant in this context, and it is essential that S&T inputs at the district level are visualised as a means of planning for some of the major sectors of our economic activities. On the eve of the Nehru Centenary Year, it is most appropriate to reinforce the planning process which was a gift from Panditji to the nation and which has achieved so much. It is necessary to formulate a Perspective Plan which gives the rightful role for S&T and at the same time more accurately reflects the aspirations of those for whom plans are meant. Given our limited resources, we must find ways and means to apply S&T to achieve some key economic targets.

- The purpose of this Perspective Plan document is to define ways and means to achieve a well-defined economic growth in key areas in the years to come, including a rapid industrial development. In an environment in which targets are set but not met, science and technology can render its greatest service by bringing to bear on planning the disciplines of defining missions, target setting, goal achievement, reproducibility and original thinking.

In this approach paper, we have attempted to indicate briefly some of the guiding principles of perspective planning in the light of the observations made above. This document is not a Plan document, but only an effort to highlight the varied factors of vital significance that have to be borne in mind in preparing a Plan and the crucial role of science and technology in planning for development. A proper Perspective Plan would not only help in preparing the country's Five Year Plans (the Eighth Five Year Plan to be specific), but also in giving better focus and direction to the efforts of our ministries, agencies and institutions.

2 Some Basic Issues

- India is in a unique position as far as science and technology are concerned. On the one hand it faces the challenge of utilising science and technology for solving the basic needs of the people such as food, shelter, clothing, health etc, and on the other its large S&T manpower is awaiting challenging tasks where one could not only contribute to the frontiers of science and technology but also use these tools for modernising our economic and commercial sectors. Furthermore, there are areas of S&T of immediate concern to us where we must become world leaders. It is this special mix that necessitates that our approach to planning must be looked at in two parts:

    - Use of science and technology in planning, and
    - Planning for science and technology per se.

- Against this background, some of the basic issues which face us today, and will continue to face us at least for the next 15-20 years, relate to the control of population, the need for increased food production, protection of the environment, improvement of human health, control of hyperurbanization and reducing unemployment. A few of the other major problems are related to energy, communications, transport and materials.

- In any plan that we make for a developing country such as India, conservation and efficiency have a big role to play. We must combine the efficient use of natural as well as human resources if we wish to achieve spectacular goals. Science and Technology should be applied to maximise conservation and reduce wastage. This concept would apply to all areas and all our endeavours related to human resources management and development, energy, water, food, agriculture, fertilizers, insecticides and so on. In certain crucial sectors such as energy there may be a necessity for a national policy for conservation.

- Given the size of our economy and its future prospects, Indian exports and India's international trade must become a vital component of our Perspective Plan. Any such plan for exports has two important goals. One is earning a larger share of international trade, and the other, generating employment for manufacturing goods and services for nondomestic markets. Increasing our export market will become possible if we take initiatives in certain sectors and this would require S&T inputs.

- The plan to upgrade existing industries in order to make them domestically attractive as well as export competitive will not happen within a short time frame. This process must however start due to the compulsions of our own economy, and it is critical that there is an export focus which is in tune with the rapidly changing global scenario. In considering international trade one cannot ignore global competition, especially from our Asian neighbours.

- While the industrial growth we are experiencing may be considered reasonable, our technological capability has not necessarily improved as much as expected. The desired impact of R&D on industry is yet to occur. Then, there are problems related to modernisation, productivity and the competitiveness of our industry. While tackling these problems, our perspective plan should take all these realities into account.

- It is estimated that by the year 2000, about 70% of our population will be less than 35 years of age. S&T can play an important role in providing jobs to our vast population. It is not enough if mere employment is provided. Our people must develop pride in their professions and the all too important scientific attitude. It is only when a large majority of us have the scientific temper that the country can really hope for a better quality of life and strive towards excellence in all spheres. We have to ensure that in all our developmental plans and educational programmes, inculcation of the scientific temper should form an underlying theme.

- Many socio-economic Ministries and Departments in Government operate in a manner that is not conducive to involving S&T for improving performance and efficiency. Our administrative procedures are not in tune with the times. Furthermore, there is no accountability in the administration, a situation that is often aggravated by a lack of continuity in administrative heads. Unless we make departments/agencies/individual administrators fully responsible and accountable for our developmental programmes, it may be difficult to accomplish the desired goals.

3 A Possible Scenario by 2001 AD

- We believe that if our resources, the needs of our people, the S&T expertise and our managerial and administrative talents are all carefully interwoven, we will start producing a tapestry of change which will start meeting the needs of larger and larger sections of our people in the coming years. We are of the firm view that S&T has a major role in making it possible to bring about such a change. We could set ourselves the goal to double our gross domestic product by the turn of the century (i.e. achieve in the next 10 years what we have achieved in the last 40). The task may appear daunting, but a 5-7% average annual growth would suffice to achieve this in real terms.

- If we are successful, what can we expect by the turn of the century?
  - We would achieve a certain targeted deceleration in population growth.
  - We would have doubled our food production through a combination of application of modern biology, planning for agro-climatic zones and the use of the best long-range weather forecasting available.
  - Health for all and literacy for the vast majority would be within reach.
  - There would be major changes in our management of energy and transportation.
  - There would be better communication facilities in rural and urban areas.
  - There would be a reversal in the erosion of our ecology through S&T inputs.
  - Problems related to rural housing and selective habitat development would have been tackled adequately.
  - We would be world leaders at least in a few selected frontier areas of science and technology.
  - We would have made a major dent in lowering poverty and unemployment.

If this scenario has to be a reality, there is much we need to do; S&T has to become an integral part of our thinking and being.

4 Science and Technology in Planning

- In spite of the best efforts, the S&T component of the plan allocation of all the economic ministries could not be clearly identified during the Sixth Five Year Plan; even where identified, the utilisation of resources for the purpose was rather meagre. Part of the difficulty in identifying the S&T components of the various economic sectors is due to the fact that the demand for science and technology in many of these sectors has not been articulated through carefully structured exercises. The situation has no doubt improved during the Seventh Five Year Plan, but is still far from satisfactory. On the one hand, there is the claim that science and technology can provide valuable inputs in improving the productivity of various economic sectors, and, on the other, despite the large S&T infrastructure available, there is no demand on this sector from potential users. *We believe that it is this aspect of providing the S&T inputs in planning which needs much greater focus and attention than what has been given hitherto.*

- With the emphasis given to S&T since Independence, a massive infrastructure covering a broad spectrum of disciplines and capabilities has been built up in our educational and research institutions. However, it has often been felt that S&T has not made the kind of impact it ought to have, possibly because the crucial role that science and technology can play in planning for growth was not realised fully. The time is certainly propitious to more systematically integrate science and technology in the process of economic planning and in setting targets. In formulating a perspective plan, an orchestrated increase in efforts and ambitions needs to be built into the Eighth Five Year Plan and beyond.

- It is therefore felt that some of the important criteria for developing the perspective plan should be:

  - to set priorities in areas of importance as perceived nationally;
  - to unambiguously assess the national S&T capability, current and future, as applicable to various sectors of national development;
  - to explore new strategies for development and to identify those efforts that would help the country to make major strides in spite of various constraints;

- to assess the socio-political will which will be required in pursuing the plans for various sectors;
- to estimate the availability of and the requirement for resources in each specific sector; and
- to identify the social and managerial inputs required for achieving the objectives of the Plan.

- Serious efforts would have to be made to deploy the vast S&T resources available for achieving the national objectives of providing the basic needs such as food, shelter, clothing, health, education etc. At the same time, we must build and modernise our infrastructure in the major service sectors such as transport, communications and energy which are vital to the overall socio-economic growth of the country. We believe that in the past these sectors have not received adequate S&T inputs during the process of planning, and have therefore slowed down the progress which could have been made through these sectors.

- An approach to provide the required S&T inputs to planning should deal with the following two aspects:

  - S&T for providing basic needs; and
  - S&T for strengthening infrastructure support.

The guiding principles for planning have generally been to emphasise programmes which promote foodgrain production, increase employment opportunities and raise productivity. In the context of equity and social justice, it becomes necessary that all efforts are made to provide such basic human needs as health, food, shelter and environment. If S&T inputs are carefully planned, it is possible to meet the requirements of basic needs in a planned manner as has been demonstrated in the case of foodgrain production. Then, there are resource areas such as energy, transport, communication and materials which are most crucial for progress and development, where only through a judicious planning through S&T will we be able to meet the developmental objectives and the cherished goals of this nation. The on-going technology missions on drinking water, immunisation, oil seeds, communications and literacy have been set up to solve some of the pressing problems, but there is need for constant vigil to avoid and eliminate the crisis situations frequently developing in the country in relation to essential requirements. In the following sections, we dwell on some illustrative efforts which could be made in the areas related to the basic needs as well as in some other areas of importance for economic growth and for improving the quality of life.

4.1 Population & Health

- The mid-term appraisal of the Seventh Five Year Plan is alarming. It shows that the rate of our population growth continues unabated. In other words, in spite of the enormous amount of work done with social, S&T and modern communications inputs, the end results have not been achieved. We face the frightening prospect of an uncontrolled chain reaction into the next century with the inevitable catastrophic consequence. This aspect must receive the topmost priority in the perspective plan.

- The solution of the population problem requires a strong political will, appropriate socio-economic measures and modern managerial and organisational skills. Newer approaches such as vaccines or controlled release drugs will not be available till the turn of the century. There are conflicting reports regarding the present status of fertility antigens, and vaccination as a means of fertility control is today primarily experimental. Long-term safety aspects related to auto-immune diseases and teratogenecity remain to be answered. This scenario puts a major limitation on the S&T inputs available in this area. However, this equally strengthens the case for renewed and massive S&T efforts in developing new methodologies. If necessary, we must show our willingness to draw upon global expertise wherever appropriate. Modern communication technology should be made an integral part of the programme. In general, there must be a resolve to tackle this menacing problem on a war footing.

- As a result of our planning efforts so far, substantial quantitative changes have been achieved in the field of health but without a radical qualitative transformation. Thus, the average life expectancy has creditably increased, maternal and infant mortality reduced and some communicable diseases partially controlled. An infrastructural chain for health care delivery, even to the remotest areas of the country, has been established. These efforts have been further supplemented by the Technology Mission on Immunisation of the vulnerable population. However, the curse of malnutrition, unhygienic environment and communicable diseases still persists. Simultaneously, noncommunicable diseases, generally believed to be associated with developed societies, have already acquired epidemic proportions. Therefore, in our future planning, while we need to strengthen our efforts in controlling communicable diseases, especially with the application of biotechnology, we should initiate action to tackle the emerging problems of noncommunicable diseases like cancer, cardio- and cerebro-vascular diseases, traffic accidents, drug abuse and diseases due to occupational and environmental toxins.

- We should also anticipate and work towards providing health care for the hundred million or so people who would be above the age of 60 by the year 2001 AD. Furthermore, while planning, we must be conscious of the urban and rural needs that are distinct, and take region-specific health care and delivery to the district level with the equipment required to derive maximum advantage.

4.2 Food

- One of the most important achievements of S&T in India has been its role in the green revolution brought about by developing high-yielding crop varieties and the package of practices for their full expression. This itself was made possible by a strong political will. However, the scenario for the coming years is rather alarming unless food production increases from the present annual figure of 150 million tonnes to 180 million tonnes by the start of the Eighth Five Year Plan and then to 300 million tonnes by the turn of the century. If this does not happen, India is likely to face a food crisis that will be reminiscent of the 1960s. Such targets cannot be reached without new scientific breakthroughs backed up by an overhauled, vibrant and innovative research and laboratory-to-land management.

- Major S&T inputs will be needed to get breakthroughs in achieving higher genetic production potential, efficient use of plant nutrients, soil and water management, tissue culture, arid zone cultivation etc. While expanding the irrigation facilities, greater attention will have to be paid to the improvement of drainage so that the soil-plant relationship is not lost sight of. Constraint analysis for the unsatisfactory increase of production in irrigated areas should be taken up on a priority basis. Urgent steps should be taken to grow crops suiting different agro-ecological conditions so that the concept of specialty agriculture can gain ground and all crops are not grown in all areas. Improvement of productivity level of rain-fed agriculture, with emphasis on improved breeds with high genetic potential for productivity, is another crying need in this area. Whereas the problem with oil seeds persists, the one on pulses is beginning to assume alarming proportions and may need attention on a mission mode. Establishment of downstream food processing industries will help in preservation and value addition and in turn will lead to higher profitability for the farmer and greater opportunities for rural employment.

- Tapping the source of vegetables, fruits and also food of animal origin is another priority area. Modern S&T inputs in food storage and transport are crucial, considering the enormous losses that now occur and that the country can ill-afford.

4.3 Housing

- The congenial surrounding of a home is necessary for an individual's growth and also for national economic growth. The provision of urban and rural housing is a complex issue with the question of urban land reforms, difficulties in providing serviced land etc, being quite important. We must realise that a major amount in housing is spent on building materials. It is here that S&T can play a major role. Whereas spectacular advances have taken place in the general area of application of new materials in sectors such as transportation, communication, energy etc, as regards building materials there has not been much progress. An examination of the present production of conventional building materials in India shows that there is a major shortfall in practically all areas. A significant breakthrough in the S&T linked to the development of low cost and alternative building materials is necessary if we plan to fulfil the resolve of providing shelter for all our people.

- Nearly 60% of the rural population in India will continue to depend on mud and thatch for housing for at least another 2 to 3 decades. However, there are possibilities of creating improved housing by upgrading these materials with polymers, which will not only improve their structural attributes but also durability. The combination of providing rural housing with appropriate ecological plans and meeting domestic energy needs should be a major focal point for village and block level development programmes which could be the quintessence of district level planning. Although over the years, S&T has provided varying inputs and models for rural housing, these have not been used extensively because of the problems of delivery on the one hand, and, on the other, issues of architectural and civil engineering codes which need to be reassessed and reexamined. The issues concerning housing in rural and urban areas, and eradication of slums in the latter, are different and will require solutions for different approaches, regarding materials for example.

- Continued usage of certain traditional materials in building construction is likely to have disastrous consequences. Let us take wood as an example. We know that our resources of wood are fast depleting. It is likely that wood will not be a common material for construction in the near future. Yet, when we consider that several million houses would be required in the next few years, to plan for such constructions without the use of wood appears to be a formidable task. We have not given sufficient thought to the replacement of such a common material as wood. In the future, we will require several million doors and windows for the houses to be built. Use of other types of materials such as glass, polymers and metals as structural materials has not been fully explored and included in our plans.

4.4 Ecology

- Continued intensification of resource use in India has been pursued in a manner that has led to a depletion of the capital stock of renewable resources. Furthermore, the costs of environmental degradation accompanying the intensification of resource use have been largely borne by the weaker sections of our society, while the benefits have accrued to those already better off. S&T inputs in this area are urgent and crucial to change this unsatisfactory scenario.

- Collection, analysis and interpretation of information concerning all aspects of the environment, which is the mainstay of environmental research, should be a vital component of our scientific enterprise, but is largely missing today. It is an endeavour calling for a massive, decentralised effort. While this is fraught with difficulties, it affords a unique opportunity to involve large numbers of our people in a meaningful scientific effort. Only such an effort would furnish the required background information and make possible a holistic plan for resource use that could enable us to turn back the tide of environmental destruction.

- The selection of soil-specific and region-specific plantlets, and their propagation and distribution through appropriate nursery practices, calls for massive deployment of S&T management throughout the country. The degree of social involvement necessary for success in this area is possibly the highest, next only to population control. In view of this, our scientific effort needs a radical reorientation of its focus on the problems of the environment at the field level, and efforts to bring in our vast network of educational institutions and voluntary agencies as active participants in science and technology assume crucial importance.

4.5 Energy

- Energy has already been recognised as an essential element in development, with practically 30% of the Plan outlay earmarked for this sector in the Seventh Five Year Plan. The demands for energy in India will continue to increase in view of the growth of agriculture and industry. There appears to be some imbalance in terms of the availability of power in different regions. S&T has a key role to play in the energy sector covering all conceivable areas including exploitation of primary sources, conversion, transmission, distribution etc. Unfortunately the usage of S&T in the energy sector has been unsatisfactory. Presently, coal, oil, natural gas, nuclear energy, renewable resources etc contribute to the energy sector. There is an urgent need to work out a national energy policy so that the role of each of these could be properly delineated in the coming decades. Such a policy is also necessary because of the crisis situation in certain parts of the country where there seems to be no hope of getting sufficient electric power in the next few years.

- In the area of coal there is growing concern that the average calorific value of the available noncoking coal is declining; coal beneficiation should therefore receive top priority. Experiments on in situ gasification to enable power generation at the pit heads should be encouraged whenever appropriate. Natural gas is emerging as a major energy source, and policy regarding its usage to meet energy and non-energy requirements needs to be clearly defined with a long-term perspective that keeps material and energy conservation in view: there is an urgent need to define a long-term natural gas policy. In the case of liquid fuels, the demands on middle distillates will continue to increase and major S&T inputs are needed for the development of new catalysts and processes, which do not interest the western world. In the area of nuclear energy, the country has developed good capability but we will have to take a realistic view of the net contribution nuclear energy can make to the total energy scenario in India in the coming decade.

- About 40% of the country's energy consumption is derived from non-commercial sources such as fuel-wood and agricultural and animal wastes. Biogas chulahs with improved energy efficiency are critical. The importance of S&T in such areas should not be underestimated, since this will bring in a change in rural energy consumption patterns and will have a direct impact on the continuing fuel-wood consumption and its devastating ecological consequences.

- Millions of two and three wheelers will be on Indian roads in the coming decades. Mixture short-circuiting in the present day two and three wheelers results in poor energy efficiency and very high unburned hydrocarbon emissions. If the engine designs are not suitably modified, almost one million tonnes of hydrocarbons will be discharged into the atmosphere by these vehicles as we reach the year 2000 (practically 15% of the total gasoline consumption in the country by the time).

- Finally, the development of the energy sector has a high probability of success with the help of S&T inputs, the presence of a vast market, and the availability of certain material and human resources. India should be in a position to become a leader in a variety of energy technologies and a major supplier of heavy power equipment in the world.

4.6 Transport

- All forms of transport are severely strained today because of the extraordinary demands being placed on them. A good transport system will not only quicken industrial growth, but will have wide ranging repurcussions on the distribution of food, petroleum products etc, removing the isolation of specific areas in the country (for example the North-East) and, in general, promoting national integration.

- Development of energy-efficient practices, technological upgradation of the present modes of transport and promotion of a multi-modal transport system are of top priority. S&T inputs in these sectors will be of key importance. The railways continue to carry the main burden of transport in India. There is tremendous scope for using S&T in modernisation and upgradation of railways, including signal controls, use of new light-weight materials and technologies in fabrication of railway coaches etc. In the case of road transport, again there is scope for development and usage of new road building materials (for instance, modification of asphalt by polymers to impart more desirable characteristics), modern methods of road construction etc. The automotive sector in India has undergone a major transformation, but S&T inputs to make sure that we have fuel-efficient, environmentally clean and modern vehicles on the road need to be defined and used. As far as buses are concerned, both chassis and bodies continue to be built with age-old and outdated technologies. There is immense scope for improving riding comfort and reducing fuel consumption. Technological upgradation in buses is badly needed.

- New strategies for transport also need to be planned. An important area that needs urgent attention is pipeline transport, which will ease the load on the conventional transport system. Already some progress has been made in transporting gas, petroleum products, minerals etc, but there are other sectors where this mode of transport could be introduced. One of the key areas is coal. There is scope for conveying 15 to 20 million tonnes of coal by this mode over distances of the order of 50 to 100 km. This will not only be an energy-efficient mode of transport, but will also reduce the pressure on the railways, especially when wagons have to be used for short distance transport.

- We must develop the S&T base required to utilise the emerging technologies in the fields of civil aviation and inland waterways, the latter particularly because of energy efficiency.

4.7 Communications

- Telecommunciation is essential to our national development and is indeed a resource for tomorrow. This area is dominated by complex national, developmental, operational and service issues. The national mission on better communications has proved to be a step in the right direction and its objectives are being enlarged to fit into the overall priorities and targets for the year 2001. New strategies in terms of increased accessibility, improved reliability, development of rural communications, building of national networks, offering new services in urban areas, utilising advanced technology etc have been already incorporated in the Plan.

- Although there is some cause for satisfaction in the way we have planned and moved ahead in recent times, we must realise that communication technology is changing very rapidly. There may be a need for examining all the S&T aspects in terms of actually incorporating the results of research, design and development work in improving communication facilities. Methodologies to integrate appropriate elements from rapid technological developments in satellite communication, optical fibres and photonics as a part of the overall plan are especially important.

4.8 Materials

Materials, both advanced and traditional, pose yet another difficult challenge today. The absence of certain materials may in fact be the biggest bottleneck in our progress during the next few decades. It has been said that the possession and understanding of materials and the ability to use them are the determinants of a civilisation. Materials today figure extensively as an enabling parameter in nearly every system associated with modern technologies in a wide spectrum of sectors like heavy engineering, transportation, aerospace, power generation, microelectronics and bioengineering. In each of these sectors, progress has been aided by a continuous development of critical materials with improved performance capabilities. Invariably, the shaping of these materials in the form of components or devices under production conditions has called for development of new, expensive and complicated processing methods. On the one hand, the situation is quite mind-boggling in terms of the bewildering variety of basic materials (metals, intermetallics polymers, ceramics, glasses), their combinations (alloys, blends and composites), the demands of advanced technological systems and the related processing and manufacturing techniques On the other hand, the scenario is fascinating because of the potential of the role of scientific inputs in materials development, the commonality of concepts that underlie seemingly diverse materials (leading to substitution for conservation of materials, e.g. plastics in place of wood packaging, composites in place of conventional structural materials, and optical fibres in place of copper cables in communications), the challenge to innovate processing methods and the need to generate new design methodologies. The prospects become astounding as the materials engineer sets out to model his products on the basis of nature's own handiwork.

- Materials are now being recognised as one of the basic resources of mankind, ranking along with living space, food, energy and human knowledge. The growing awareness of the paramount importance of materials development is reflected in a number of initiatives launched by policy-making bodies of governments in advanced countries. It is in this context that an advanced materials programme for our country should be formulated, keeping in view not only the needs of our technologies, but also the national resources position and the indigenous situation in the area of materials processing. Clearly, there arises an essential need for selection of materials for concentrated research, for integrated development and for establishing manufacturing processes.

- Leadership in the materials field is not a new experience that we shall be reaching out to. There are several instances of achievement of ancient India (Chola bronze idols, the Delhi iron pillar) that cause us to recognise that we have a rich heritage in the materials field as well. More than three centuries ago, during 1660-1670, India exported to Western Europe nearly 6.5 tons of 'Wootz steel' in small lumps of unspecified size made by the native crucible process in the Deccan. The famous Damascus swords were made from this Indian steel. The inspiring question is, what can we attempt today in the field of advanced materials that will match the Wootz steel record?

4.9 Manufacturing

- Productivity is central to industrial growth. In the most successfully industrialised nations, ''electronification'' has been demonstrated as a key strategy in the modernisation of manufacturing to achieve at once higher productivity and enhanced quality. The advent of microprocessors has aided process engineering in chemical, metallurgical and other industries and facilitated better control of process parameters for higher precision in operations, data acquisition and application. New technology developments in computers, lasers, fibre optics and robotics have resulted in computer-aided design (CAD) of engineering products and systems, computer-aided manufacturing (CAM) leading to integration of the entire manufacturing area through computers (CIM) with benefits to productivity in a manner unimagined hitherto. Similarly, application of scientific principles to business in the areas of forecasting, marketing, production planning and control, materials and inventory control, financial planning and management, maintenance, quality management and productivity monitoring is having a marked effect on achieving efficiencies higher than ever before. There is considerable room and opportunity for planning for these inputs in indigenous manufacturing.

4.10 Information Technology

- Information technology will play a key role in all our national endeavours and its importance has to be properly recognised in the planning process. Thus, for instance, health information systems will be important in generating and disseminating high quality data useful for analysis, policy formulation, and design of suitable health-care delivery systems. Similarly, accurate meteorological data coupled with modern weather prediction techniques and transmission of data through telematic networks, with suitable back-up agricultural support systems, will imply a sea-change in our ability to plan our agriculture in an optimal way for a given set of weather conditions. Similar examples can be cited in several other areas such as transport, energy, technology for industry etc. It is therefore necessary that appropriate information systems are provided for in our plans for all the important sectors.

5 Science & Technology in Industrial Development

- The industrial base in India has been expanding very rapidly with enormous diversification in recent years. The efforts of the Government in recent years to accelerate the pace of growth by eliminating constraints are beginning to pay dividends. Increase in industrial production has been satisfying, but one has to realise that industrial production and technological capability are not synonymous. The latter depends so critically on the industry's ability to make use of high level inputs arising out of its own R&D capability. The health of industrial R&D in India is a matter of great concern today. Although over a thousand R&D units exist in both public and private sectors, only 0.7% of the sales turnover is invested in R&D, most of it by the Central Government. The output from most industrial R&D is poor, both in quality and quantity, and is certainly not adequate to meet the challenges of today, let alone those of the coming decades.

- It is recognised that the advent of modern industrial development and culture in India is hardly 40 years old and is still evolving. Till very recently, due to the shortage of resources, industrial development was closely controlled and directed by the Central Government. In this policy, social and economic goals had significantly greater priority compared to efficiency and competitiveness. But we see no conflict between the two. Industry today faces the urgent need for modernisation and improvement of productivity, and for developing the ability to withstand competition. In certain cases, these factors could determine the very survival of the industry. It is not therefore difficult to see how the improvement of the state of industry is closely related to bettering employment opportunities and to achieving socio-economic goals.

- Although there are some healthy trends and some examples of successes in R&D in selected sectors of Indian industry, these are small in number and not proportional to the inputs. The establishment of R&D units in the private sector, in most cases, has been triggered by tax concessions offered by the Government rather than an intrinsic feeling of need for R&D. In the name of R&D, only the mundane functions of quality control and analytical services are often carried out.

- We should also think of the village and small scale industries, which, apart from providing employment, make a major contribution to manufactured exports. There is an urgent need for modernisation in industries related to coir, silk etc, so that productivity and product quality improvement will help them to avoid stagnation. This can be achieved only through appropriate S&T plans.

- There are several unhealthy trends due to which S&T has not contributed to industrial growth. Lack of long range corporate plans for R&D and dominance of defensive R&D linked to depackaging of imported technology are common features of much of the industrial R&D in the country. In the innovation chain from concept to commercialisation, support in the latter part of the innovation chain by a 'product champion' at the senior management level becomes critical. In the absence of research directors on the Boards of Directors, it is difficult to complete this chain with tangible results. External inputs in planning and evaluation besides contacts with high-level academics have been missing. In the case of evaluation of R&D, short-range commercial considerations have dominated the evaluation. Inputs' in R&D rather than 'outputs' have been taken to be the indices of performance.

- It is often argued that our production in many sectors is not of sufficient magnitude to warrant inputs of R&D. This is clearly fallacious. We are the largest producers of bicycles, fans and sewing machines in the world and yet no R&D inputs have gone in these areas. We are the largest producers of sugar, but again our technology remains old and outdated. We are not competitive where we should have been - say, in the area of garments (where we account for only 1% of the world market with one-fifth of the world's population), and steel (ours is among the most expensive in the world, although we have excellent iron ore), power generating equipment (with a significant share of the world market today we could have been among the world leaders as technology suppliers). Lack of S&T inputs in these sectors is obviously the reason for such deplorable conditions.

- The creation of the Technology Information Assessment and Forecasting Council (TIFAC) and the Technology Development Fund (TDF) are major steps forward. We must see how these can be used in promoting industrial R&D and inducing the industry to make more use of S&T. The Council has to provide advice on the technologies that we have to opt for in priority sectors. There may be a need to consider new and innovative models for cooperative research programmes supported by a sector of industry with common goals. Traditionally planned and managed research associations such as in jute, fibres etc have been failures and have not been able to prevent sickness in the related industries. New thinking is therefore urgently needed. Even trans-national programmes in chosen sectors of industry with common goals should be promoted in areas of mutual interest. We must recognise our intrinsic strengths and exploit these. Considering the limited materials and financial resources, it is important to rely on India's potentially most valuable resource, viz. scientific and technical knowledge. Knowledge-based industries such as software production present certain advantages in the Indian context since the usage of primary resources is low but that of human resources is high. We must systematically plan on exploiting this resource for national benefit. In addition, the atmosphere should be such that good ideas for initiating industries get support through venture capital and other means. Many novel efforts requiring relatively small investments may enable us to become competitive internationally in certain sectors.

- The lower productivity of a worker in Indian industry in comparison to those in advanced countries is often attributed to factors that are totally non-scientific. However, major changes in human and capital productivity in industry can be brought out by S&T inputs, both directly as well as indirectly. In more direct terms, improved productivity, higher utilisation of plant capacity, improved product quality etc will directly reflect on better human productivity. On the other hand, even indirectly, injection of the scientific temper in an industrial worker can impart major benefits.

- Finally, the state of application of S&T in industry will improve only when we can understand and stimulate those factors which will kindle the innovative instinct and force the pace of R&D through competition, market pressures and reward for achievement.

6 Planning for Science & Technology

- We must distinguish between planning for science and technology, which is our concern in this section, from science and technology in planning which was discussed earlier in this paper. S&T must progress and advance if it hopes to be the beacon for our economic development. Planning for science and technology has goals in the longer term; its basic objectives are to improve the climate in which S&T work is undertaken in the country, provide a pool of talent and achievement that in later decades may even determine the directions which our plans will take, and retain a certain flexibility in our approach to ensure that in the long term options available to the country will not be limited because of lack of manpower or know-how in areas which assume importance beyond what may have been anticipated.

- If our vision for the new century is that India will win for itself a position of pride and respect in the world of science and technology by virtue of its scientific achievements and of its presence as an internationally competitive force in at least some areas of science and technology, there are certain considerations we cannot forget. To achieve these goals there are first of all two traps to be avoided. The first is to pursue everything that is 'important', 'interesting' or even 'feasible'. The second is to over-plan (especially in science but also in technology) to a degree where flexibility of response is lost and new opportunities cannot be seized.

- It is suggested that the criteria for choice of areas in fundamental research must therefore be promise of achievement of excellence, and the existence of special advantages that India or Indian scientists may possess, either because of our situation or because of resources specially available in the country. As examples of advantages of situation, we would suggest such subjects as the dynamics of the monsoons, the science of Himalayan geology and the Indian Ocean, the science of materials (especially those that are abundantly available in the country, such as titanium, zirconium, and rare earths), tropical diseases, plant resources in medicine, solar and other alternative sources of energy etc. Among those areas where we may have an advantage because of our manpower resources or the strength of our current research effort, we may mention sophisticated software development, parallel computing, numerical mathematics, superconductivity, photonics etc. Similarly, it is essential to create institutions to preserve what may be called national 'scientific property'. In this category would be (a) a human health databank, (b) a national germ-plasm bank, (c) a centre for the protection of national scientific property rights, (d) information banks for networking of Indian scientific talent in the country and abroad, and in general (e) centres of informatics and networks that will provide vital information that the nation needs to ensure that the priorities suggested above get the attention they deserve.

- Instrumentation has to be given serious attention and support in order to promote experimental research as well as innovative R&D. Instrumentation is a crying need in our schools, colleges, hospitals and industry. Without an instrumentation culture, it will be difficult for us to provide proper support for our proposed efforts in high science and technology as well as to our educational and medical system. Know-how for developing most of the instruments already exists in the country, but linkages between institutions for the purpose of producing the instruments on an industrial scale are poor.

- In India, planning for science and technology in the last 40 years has mainly been focussed around governmental support to various S&T sectors identified through government departments. As an indication of political commitment to growth of science and technology in the country, several government departments and agencies have been set up over the years dealing with Atomic Energy, Space, Electronics, Agricultural Research, Medical Research, Ocean Development, Non-Conventional Energy Sources, Biotechnology, Industrial Research and Defence Research. These S&T organisations have pursued the growth of disciplines allotted respectively to that sector of science and technology. Recognising the wider scope of science and technology and with the continuous emergence of new and inter-disciplinary areas, the Department of Science and Technology was created precisely with the view of cutting across sectors to evolve, in a co-ordinated manner, various policy guidelines necessary for the growth and application of science and technology in the country. These government agencies have pursued their programmes through autonomous institutions attached to them as well as by supporting research and development activities in academic and other research institutions through financial support on a time-bound project basis. Certain capabilities in fields such as nuclear research, space research, defence research, agricultural research, medical research etc have grown as a result of efforts of these S&T agencies through the activities pursued in autonomous research laboratories and academic institutions. The growth of research in our educational system has partly been encouraged through these S&T agencies. While these S&T agencies have taken the responsibility for evolving major national projects and missions in well defined areas, there is a pervasive feeling that the knowledge generated through governmental S&T efforts is not being adequately utilised in the growth of the national economy or of productivity in various economic sectors and industry. Even the S&T agencies mentioned above have not been able to fully participate in the economic development of the country through well-planned mechanisms of integration of science and technology with development planning. As was indicated in the previous sections, the need for S&T in planning is increasingly being felt, and to meet this need it is necessary that our planning for S&T is done with a view to dovetail our S&T priorities with our national needs on the one hand and on fostering excellence on the other. It is therefore imperative that our national S&T agencies prepare well through our perspective plans which will not only bring together expertise of the highest kind with excellence in selected areas of national importance, but also make a meaningful contribution to the growth of productivity of our wide ranging economic sectors.

- While planning for S&T activities of these specialised agencies, it is necessary to set inter se priorities so that the growth of various S&T sectors does not take place in isolation and at the cost of one another, but is harmonious in all the various S&T sectors relevant to national needs. In this process, the inter se priorities of our Plans have not been properly set, and the mode of allocation of resources has been based more on the absorptive capacity of a particular S&T sector than on the identified priorities of economic growth. The perspective plans of individual S&T sectors would therefore have to take this into account; at the same time, there is a need for a national mechanism to decide our national inter se priorities amongst the various S&T sectors which have grown during the last 40 years.

6.1 Some Aspects of Higher Education and Research

- Normally, the development of new S&T might be expected to involve, and indeed proceed from, the University system. It is widely recognised, however, that education in high science and technology today presents a discouraging picture. There are numerous reasons for this state of affairs, some having to do with complex social factors. It needs to be recognised first that the university structure in the country has rapidly expanded and made available higher education of a certain quality to a large number of poeple, and this should be taken as a welcome sign of wide awareness in the country of the social and cultural value of education. At the same time, however, it is important to realise that the vision we have demands education of a quality that has not been possible in the prevailing academic system. A large number of universities are ill-equipped, and lack that actual demonstration of excellence in teaching and research which is essential for promoting achievement. On the other hand, the universities turn out a large number of graduates many of whom end up by being unemployed or underemployed, being perhaps even unemployable. Some of the following measures to improve the situation with regard to education need to be considered while planning for S&T.

- While undergraduate education in engineering and technology, through such institutions as IITs and the Regional Engineering Colleges, has achieved a reasonably high standard in many cases, the quality of undergraduate science education available in the country tends to be poor. The factors mentioned above, as well as the extreme rigidity of the science curricula, have promoted substandard science courses in the country. A new institutional approach needs to be introduced to provide education in science, comparable in quality with what the IITs do in engineering. Such an institutional structure should be linked to the higher institutions of learning in the country, for example, TIFR, IISc, the IITs etc, drawing upon the human and material resources of these institutions to ensure that the quality of education provided remains high. Such a system would have the autonomy to devise its own curriculum and examination system independently of the 'norms' that govern the rest of the academic system in the country. We should not be afraid if certain centres of higher education and research become elitist.

- In many areas of science and particularly in engineering, a new system of links between universities and national laboratories needs to be forged. (By national laboratories here we mean all those institutions that work under a variety of different public agencies such as CSIR, ICMR, ICAR, Defence, Space, Atomic Energy etc.) Many of these institutions have received substantial support since Independence, and the time has now come for them to plough part of that input back into the university system by such joint ventures. The organisation of the national laboratories permits them to undertake major projects of a kind that are difficult to undertake in most universities. The facilities available and the expertise built up can promote such excellence in research. On the other hand, these laboratories do not have easy access to the bright young talent that many universities still attract but cannot utilise because of lack of exposure, opportunity, or facilities. A system of joint centres of the kind that have so effectively been organised by CNRS in France, with joint appointments and shared research programmes, would seem to be particularly appropriate in India as a cost-effective and rapid method of raising the levels of university education and of enhancing research productivity in the national laboratories. Indeed, some national laboratories with a strong programme of research should in fact be encouraged to provide training programmes at Master's or higher levels involving substantial contribution in research. Selected laboratories could even be permitted to grant degrees to those trained by them, if necessary through a nearby educational institution (by formal recognition or affiliation). Many areas of technology (for example, parallel computing, turbomachinery, materials technology) are probably best developed through such programmes.

- The UGC has evolved various methods by which selected departments or groups in universities are given special assistance or support to promote their research programmes. This is a laudable step, but we would like to recommend that the concept be extended to promoting centres of excellence around individuals or small groups of scientists and engineers instead of a whole department or institution. This will enable scientists and engineers with a proven record of achievement and bright ideas for future research to get the modest support that will make it easier for them to undertake projects involving higher scientific risks as well as high potential rewards. Such centres should be encouraged in universities as well as national laboratories.

- In addition we would suggest that, perhaps as part of the celebrations of the Nehru Birth Centenary, two centres of advanced studies may be set up. One of them would be for demographic studies, and will bring together the best talent and opinion in an effort to devise optimal strategies for population control and to constantly assess the results of our efforts in that area. The second centre could devote itself to certain chosen aspects of basic science, somewhat like the institute of advanced studies in Princeton, providing an environment where the best minds would be free to pursue their research ideas.

- There are now a variety of institutions and agencies in the country supporting research. The availability of multiple sources is a healthy feature of the science scene in the country. Funding should be available for ideas, irrespective of the area proposed to be investigated, in particular where such areas fall between disciplines or are unusual or involve higher risks than are normal when seeking support for research projects, provided only that the record of the individual or group concerned has been demonstrably excellent.

7 Modus Operandi and Strategies for Action

- An analysis of past experience shows that while the process of planning may have been sound, the implementation mechanisms and related strategies have not been adequate. Ambitious targets have generally been set but for achieving them, the modus operandi has not been satisfactory. We believe that it is in this area of implementation (of how to "make things happen") where the perspective plan should lay great stress. Science and technology have a role to play in evolving proper methodologies and in increasing productivity and efficiency. This faith is strengthened by the fact that in the past, whenever well-defined tasks were assigned and a dynamic leadership along with a responsive managerial system introduced, the S&T sector has risen to the occasion and achieved the set goals. The examples of the 'green revolution', exploration for oil and natural gas, the atomic energy and space programmes, and more recently the experiments in the field of telecommunications through institutional mechanisms like C-DOT testify to this statement. It is based on this realisation that the Prime Minister has initiated a few societal and technology missions as well as several technology projects to be executed in a mission mode. These have already started to demonstrate a greater chance of success than was possible under the earlier implementing processes. Some of our glaring failures, for example, in the control of population, eradication of communicable diseases, preservation of our environment and development of self-reliant indigenous technology at least in some areas, are not primarily due to the failure of science and technology but are probably due to poor management and inappropriate mode of execution. It is thus necessary that some of our more difficult tasks are tackled in the mission mode.

- In order to provide a greater degree of success in our future Plans, it is necessary to identify priority areas, unambiguously assess the available science and technology capabilities, define time-targeted goals, determine the relative role of social, economic and political factors and provide the appropriate managerial inputs. Coupled with this approach, there would be a need for an independent machinery to periodically monitor the progress achieved and introduce mid-course corrections wherever necessary. We therefore believe that a strategy for action and modus operandi for implementing these strategies have to be defined for the two basic aspects of planning discussed earlier: (a) S&T in planning, and (b) planning for S&T.

- Traditionally, the economic sectors are grouped under the various departments and ministries of the government but, by and large, they do not have strong linkages with the S&T infrastructure in the country. As a result, S&T inputs for these economic sectors have never been seriously considered. It is necessary for every concerned economic ministry to draw out a perspective plan for the next 10-15 years with clear targets and identify specific science and technology inputs required to achieve the targets set.

For this purpose, it will be necessary that every economic ministry sets up a think tank in the form of a Science and Technology Advisory Committee which undertakes this task. While some of the economic ministries have initiated the setting up of such think tanks, these need to be activated and given specific tasks and responsibilities. Such advisory committees should be given a proper status so that the advice does not get ignored; the committees should be able to report to the concerned minister directly. As part of the S&T plans of these economic ministries, clear cut demands must be placed on the existing S&T sector including educational and research institutions in the form of time-bound and need-based projects and missions. The nexus between the S&T infrastructure and the economic ministries has to be strengthened and to a certain extent forced on the system. The user economic ministries should allocate S&T budgets for such activities and utilise the existing infrastructure available in the educational and scientific research institutions. The system should also encourage the academic community to take up challenging tasks to tackle socio-economic problems which would be assigned to them by the economic ministries. The S&T budgets of these ministries should not be diverted or cut for extraneous reasons.

- By the turn of the century we need to produce around 300 million tonnes of foodgrains to meet the requirements of India's growing population. The increased production will have to be raised from the existing cultivable area. For meeting this target, management of the production package in areas suited for intensive agriculture will have to be optimised, improved production technology will have to be developed for rainfed agriculture and new techniques for upgrading the genetic production potential of our major food crops will have to be researched on and perfected. Simultaneously, attention will need to be paid to harnessing the potential offered by fruits and vegetables, acquaculture for fish and the marine food reservoir. For this to be effective, attention to food processing for preservation is crucial. Food should be a national mission for the next decade.

- Unabated population growth, as at present, not only adds to the economic burden for all developmental activities, but also reduces the impact of economic growth on our society. Therefore, for the success of our planning, population control becomes the most urgent necessity. S&T inputs are only one of the important elements necessary for this purpose. A comprehensive national mission, with strong political backing and appropriate socio-economic measures, fully utilising the available scientific know-how, simultaneously making efforts for developing new methodologies, and supported by modern communication technology and managerial and organisational skills, is essential for success in this most difficult area. Population control should also be a national mission for the next decade.

- In addition to drawing specific action plans for S&T inputs in the traditionally identified economic sectors, special measures would have to be taken in areas such as conservation, efficiency and export, where S&T inputs could make a major impact on our national development.

- The conservation of soil should receive very high priority. It is claimed that in India every six months more top soil gets washed away than has been used to build brick houses across the country in one year. In the highly grazed Shivalik Hills 6 cm of top soil representing nearly 2,400 years of local ecological history gets lost every year. Intensive agriculture without proper supplementation is leading to alarming depletion of soil fertility. Indeed the loss in terms of fertilizers equivalent is considered to be a substantial fraction of the annual fertilizer production in India.

- While on the subject of fertilizers, it needs to be emphasised that by using modern S&T inputs a significant amount of conservation is possible. We can make careful choices of technologies. For instance, hydrogen recovery from ammonia synthesis plants is being practised in India in only 15% of the fertilizer plants. Even with a modest 5% increase in ammonia production by purge gas recovery, it would be possible to produce additional urea equivalent to two 1,350 tonnes per annum ammonia plants saving several hundred crores. Much of the urea that is applied to the soil is lost due to leaching and nitrification. Controlled release urea could similarly offer impressive savings but we have not provided sufficient S&T inputs in this vital area to make this possible.

- Another critical area is water management and conservation. After all India is not a desert and there is a tremendous precipitation, but much water is lost through run off, evaporation etc. Water harvesting technologies will require high level S&T inputs. A national water policy is badly lacking. Such a policy should be developed and enforced with a sense of urgency.

- Conservation of food is another area of great importance. Innovative S&T inputs through scientific methods of storage, development and usage of appropriate post-harvesting technologies, improved methods of packaging of food with newly developed multilayer barrier packaging materials etc can bring in considerable savings.

- In the case of energy, every unit of energy saved is a unit of energy produced. Considering the acute power shortage we can ill-afford to postpone the development of a strategy for energy conservation and recycling. Energy audit of energy-intensive sectors has to be undertaken on a scientific basis. Utilisation of high grade energy for purposes where low grade energy could be used should be avoided. This means that it is not only the amount of energy but also the quality or grade of energy that has to be conserved and efficiently used. A major systems approach to planning of energy production and distribution with appropriate packages of incentives and penalties is urgently needed. A national agency should be made responsible for enforcing energy conservation in all sectors.

- Conservation of forests for ecological reasons (a subject touched upon elsewhere), conservation of materials and conservation and efficient utilisation of human resources should be given serious consideration. ''Conservation from oil to soil'' and ''produce more from less'' should become slogans for the coming decade. With serious S&T inputs, it is possible to meet the goals we should set for conserving and efficiently utilising the natural and human resources that this country is endowed with.

- The Sixth Five Year Plan launched an important new initiative in the form of ecodevelopment action research programmes for the Himalayas, the Western Ghats and the Ganga basin. These have involved universities, colleges as well as a few voluntary agencies. These programmes have continued in the Seventh Plan, but have not made as much headway as was hoped because the university and college structures do not permit active pursuit of field research or interaction with the voluntary sector. We should now make an all out attempt to introduce appropriate changes in the way educational institutions function to promote a culture of multidisciplinary field research on problems of local relevance. This should be followed by substantial investment to encourage active involvement of educational institutions and voluntary agencies in the area of conservation and sustainable utilisation of natural resources.

- In the vital area of telecommunications, there is already a National Technology Mission operating, with plans for making substantial improvements in the facilities and services that will be available by 2001 AD. We consider that this area is another vital infrastructural sector whose development is essential for the overall progress of the country. We propose that a Telecom Commission be set up as an apex policy and regulatory body, with the full financial and administrative powers of the Government of India and charged with the overall responsibility for modernising India's telecommunication equipment and services in as short a time as possible.

- Although there has been some research and development in the Railways, in general the total R&D effort in the transport sector in India is deplorably small. This could have a serious impact on our development plans, in both urban and rural areas. It is suggested that an intensive effort should be made to introduce S&T in the transport sector through the constitution of appropriate Scientific Advisory Committees in the concerned Ministries, utilising to the maximum extent possible the infrastructure available in the country for R&D in mechanical and electrical sciences. In particular projects should be undertaken for the design of more fuel-efficient road and railway vehicles. In major cities, planning for transport should become an integral part of urban development. In Civil Aviation an imaginative policy could now pay rich dividends to the country in terms of export as well: the large investments being made in imported aircraft for the airlines must in part be recovered through co-production arrangements and by earning foreign exchange by promoting tourism. In otherwise inaccessible areas, aircraft continue to provide cost-effective means of providing links with the rest of the country. The time has come to set up a Civil Aeronautics Board which can lay down balanced policies for the country in terms of industry for civil aircraft, indigenous technology development, co-production arrangements, flight safety, and the associated R&D effort required.

- The importance of minerals and materials has become even more vital in the context of modern technologies as well as every day life. Minerals are non-renewable and finite natural resources. The dynamics of ore reserves needs to be appreciated and reflected in constant updating of data not only of the reserves position but also on the rate of consumption and projected demand for defence and developmental needs as well as the international situation. Since minerals represent a national asset, augmentation of their production and export should be strategically managed so as to maximise return benefits. While the scientific and technological inputs into our mineral exploration activities need to be considerably enlarged there is need to appreciate that from the ore to the eventual product in the shape of materials and their utilisation there exists a chain of activities. An integrated view therefore is essential to cover the range of areas from exploration of ore reserves, mining, beneficiation and establishment of extraction processes, leading to development of relevant products and their optimal utilisation. A dynamic stock-piling policy as well as development of and support to indigenous production technologies would have to form part of such an integrated policy. There is also a clear need to have a body at the national level to launch, coordinate, review and monitor programmes in the area of advanced materials. Only a national body such as a National Advanced Materials Research and Development Board, that needs to be created, can have the necessary knowledge and authority to mobilise the existing capabilities and organise installation of additional facilities to deal with the scientific, processing and manufacturing challenges involved.

- In order to promote instrumentation in the country, an autonomous Corporation should be established. The Corporation should initially pick around ten most important instruments of use in research and industry, and produce them within the next five years in adequate quantities, taking care to maintain high quality. Important instruments required for school and college science courses should similarly be produced within a short time frame.

- Planning for export through S&T has necessarily to take into account an increasingly competitive export market and hence our strategies would have to be based on a spirit of competition where quality control would play a dominant role. Since export industry is synonymous with modern technology, value addition and competitive cost, building an export infrastructure will be dominantly S&T-based. Export commodities would include manufactured products, software, computer peripherals, minerals, biotechnology products, processed materials etc. Since world markets may differ from domestic situations, it would be necessary to establish exclusive export zones by providing ''cordon sanitaire''. Creation of such zones in places such as Andamans, Lakshadweep, Goa, Pondicherry etc should be considered. This may encourage foreign investment and foreign trade servicing India's plans without interfering with the social and economic changes in the domestic mainland. We must aim to cross at least Rs.100,000 crores for export by the end of the Perspective Plan period. This might appear to be, at first sight, a heady target. But we must for once tear ourselves away from our historical experiences and domestic preoccupations in order to add real strength to our economy. It should also be pointed out here that even in certain traditional exports (e.g. minerals), we should develop a conscious policy based on our needs as well as strengths in S&T.

- Employment, especially in rural areas, is becoming a critical problem. Downstream food processing operations, pollution-free and less energy-intensive manufacture of low cost building materials etc are typical examples of areas with vast employment generation possibilities in rural areas. Export-oriented industries will not only give employment, but also improve the quality of life and attitudes of large sections of our people.

- Science and Technology activities have not only to be promoted in educational and research institutions but should also be rapidly increased in our industrial sector. At the same time, research and development activities for industrial development should not be confined within the industry itself, but the educational and national research institutions should also appropriately participate in such programmes and carry out research on behalf of industry. Judicious allocation of specific responsibilities amongst the different institutions for industry-oriented R&D has to be prepared and adequate support provided for carrying out the tasks.

- Planning and development of S&T manpower is a major responsibility of the educational sector. Our experience so far has been that the supply of S&T manpower, though substantially large, is not adequately qualified or trained for undertaking problems of development involving application of S&T knowledge. The supply of S&T manpower therefore does not at present match the demands in key sectors of our S&T activities. With the rapid advancement and new developments in science and technology several inter-disciplinary and new areas are emerging which need a different kind of training set-up than is available in our existing educational institutions. For example, some of the major national laboratories such as BARC, NAL, NCL, NPL and DMRL should train students at the Master's and Ph.D. levels in chosen areas of advanced technology. Areas such as advanced materials science and technology, parallel computing, photonics, robotics and automation, need expertise to be built up through careful planning in the educational system.

- In our scientific institutions and agencies, there is a need for focussing greater emphasis on nurturing quality and excellence so that Indian S&T efforts would be in the frontline in new and emerging areas of science and technology. Discovery-oriented research has to be encouraged on a selective basis, ensuring that the quality is of international standards. While nurturing such types of research, efforts should also be made to see how the expertise available in our laboratories and research institutions can be geared towards solving the problems of our economic and industrial sectors. Challenging, time-bound and mission-oriented projects should be assigned to agencies/institutions in order to give better focus to our R&D efforts in our national laboratories and to improve the interaction between laboratories and industries.

- A statutory, autonomous body to support science and engineering research has to be established early and charged with the task of ensuring support for excellence in science and engineering and of giving a general direction to science in the country. This body should publish annual "science indicators"

- If science and technology efforts have to provide inputs to our planning as was highlighted in earlier sections, it is necessary to devote adequate attention to ensure a planned growth for S&T. India today is devoting roughly 1% of GNP towards overall S&T activities in the country. The total allocation for S&T activities in our Seventh Plan outlay is about 2%. We believe that S&T has to play an increasing role in the economic growth of the country, a larger percentage of GNP would have to be devoted for S&T activities over the coming decades. While quantitative estimates cannot be made for increased allocation of S&T at this stage, based on the figures for developed countries, we estimate that we need to devote to S&T at least 2-3% of GNP over the coming decades. This sum would have to be carefully allocated giving considerable emphasis to quality and excellence rather than being preoccupied with numbers alone. Furthermore, the present method of allocation of resources for the various S&T sectors does not give adequate consideration to inter se priorities but is based more on absorptive capacities; the element of selective priorities has to be brought out even for planning the S&T sectors.

- Presently, the allocation of resources to S&T activities in the States is much lower than what is being given by the Centre. While major S&T programmes such as atomic energy, space and defence research have to be undertaken by the Centre, there is still a need for the States to allocate a greater part of their resources to S&T activities than what they have been doing hitherto. There are a number of local and regional problems at the

State and District levels which can only be solved through appropriate use of local expertise and administrative machinery, and through the use of existing S&T knowledge and development of adaptive technologies relevant to local needs. A greater S&T involvement at the State level is essential if S&T has to percolate down to the local population. For this purpose, the State Councils for Science and Technology as well as their Departments of Science and Technology have to be activated.

- In order to accomplish many of these challenging tasks, we have to provide proper administrative support. Frequent transfers of officials responsible for major departments or programmes have often resulted in the absence of accountability. We have to assign responsibilities to concerned departments/agencies/individuals and make them accountable for their performance at the end of a given time frame.

- It is clear to us that not everything that we plan can be accomplished by government machinery alone. We need to fully exploit the potential of voluntary movements in crucial areas such as population control, family welfare, school education and adult literacy. It is likely that many of these tasks are better executed by motivated citizens, especially the educated women who are not yet fully utilised for the benefit of our society.

- If the above concepts of using science and technology in planning are to be effective in our future plans, it is evident that the strategies indicated above should be effectively implemented. The existing structures for S&T and planning are isolated. Even within the S&T sector there is not sufficient coordination to determine the right priorities and basis for resource allocation to different S&T sectors as well as for fundamental research in science and engineering in the country. In order to make sure that adequate S&T inputs are available for economic planning, to assist in determining national directions in S&T and to set the priorities in our plans, it is proposed that a National Science and Technology Commission (NSTC) be established. It would be appropriate here to quote the observation made in 1973 by the National Committee on Science and Technology:

> "There has been no explicit policy on the level and allocation of funds for scientific and technological activity, well over 80% of which is funded from the central exchequer. Each agency has submitted its proposals to the Planning Commission; the Commission has appraised them from primarily a financial point of view,

> endorsed the plans largely unmodified and recommended their funding to Government. Government, in turn, has accepted these recommendations and taken them to Parliament which, in large measure, has been generous and voted the funds asked for. In sum, the overall funding of scientific research has been decided more by the absorptive capacity of the agencies and institutions concerned than by considerations of the economic or social importance of the fields.
>
> The absorptive capacity of the different agencies and institutions has varied very widely. Part of the reason for this variation is the complexity of the technology handled by the different agencies, but, it has, in no mean measure, been also due to a range of factors external to the complexity of the technology and to whether or not the scientists were capable of doing good science. These reasons have often had to do with such things as the organisational flexibility within Agencies and Departments; the standing of the Heads of Agencies and other factors quite unrelated to the requirements of the national economy. The result of this essentially 'laissez faire' attitude to the allocation of funds has been a growing mis-match between the distribution of funds for scientific activity and the economic and social importance of the areas of funding.''

We strongly believe that these lacunae still persist and should be remedied effectively through the setting up of the NSTC. The NSTC would not only consider the role of science and technology in planning, but could also help in deciding inter se priorities within the various S&T sectors and consider various issues such as technology forecasting, technology import and absorption etc which are vital to economic development through application of science and technology. NSTC will involve the socio-economic and other concerned ministries in its work besides the S&T ministries and agencies. It will promote and coordinate collaboration amongst the different agencies in the country with a view to ensuring the fullest possible utilisation of science and technology for national development. NSTC will work closely with the Planning Commission.

8 Epilogue

- We have briefly described a possible philosophy for perspective planning and have suggested certain priorities. We have concerned ourselves with the essential aspects of S&T inputs to our national planning, and also touched on planning for S&T and the role of S&T in industry. The mechanisms for implementation are of great concern to us and we have made some suggestions in this regard. We believe that it is extremely important for us to succeed in our planning process, for it is only success that will vitalise our society and trigger it into further action.

- In presenting an approach to perspective planning through science and technology, we realise that no document prepared by a few individuals on a topic of such vital significance can be entirely complete. We have chosen a few aspects of crucial importance to development to illustrate how science and technology planning can be more effective and meaningful. We are conscious that there are many other areas which are likely to be of equal importance and which we have ignored. This document is not intended to be comprehensive but only illustrative and we hope that it conveys the spirit of S&T planning that we wish to suggest.

- While planning is often understood to be a highly centralised exercise at the national or state level, it has to really happen at the working level. We have to prepare plans which address themselves to the burning problems of the present and at the same time address the future. Each institution will have to work out a perspective plan with the cooperation of the working people of the institution. Each ministry, department and agency will have to prepare a perspective plan which takes into account various institutional plans. It is only on the basis of such thoughtful and imaginative exercises carried out at all levels that we can develop a national perspective and find a modality for day-to-day action and achievement.

- It is our hope that this approach paper may act as a catalyst in the preparation of perspective S&T Plans by institutions, agencies and departments. This would be a fitting tribute to Pandit Jawaharlal Nehru during his centennial year. This would also contribute to the preparation of the Eighth Five Year Plan and enable the country to achieve excellence and economic development.

Appendix-2

List of Meetings Held to Discuss the Approach Paper

Meetings SAC-PM held with the Prime Minister, Planning Commission and others to discuss/present the document on ''An Approach to a Perspective Plan for 2001 AD: Role of Science and Technology''

- Meeting with the Prime Minister on 9 June 1987.
- Meeting with Deputy Chairman and Members of the Planning Commission on 23 September 1987.
- Meeting with Prime Minister on 10 February 1988.
- Meeting with Member (Science), Planning Commission on 20 June 1988.
- Presentation of the Approach Paper in Appendix-1 to the Prime Minister on 3 August 1988. The Approach Paper was released to the press on 5 August 1988.
- Meeting with Planning Commission, Secretaries of Science Departments, Chairman UGC and others on 11 August 1988.

As decided at the meeting held with the Prime Minister on 3 August 1988, discussion meetings were organised at various centres in the country:

- Indian Institute of Science, Bangalore on 13 August 1988.
- Tata Institute of Fundamental Research, Bombay on 20 August 1988.
- India International Centre, New Delhi on 12 September 1988.
- Indian Institute of Chemical Biology, Calcutta on 7 October 1988.
- CSIR Science Centre, New Delhi on 12 October 1988.

Over 150 professionals, representing a wide cross section of opinion, were invited to participate in these meetings.

Part 1

Frontier Areas of Research and Development

1

Advanced Materials: National Priorities

It is a recorded fact that more than three centuries ago, during 1660-1670, India exported to Western Europe nearly 6.5 tons of 'Wootz steel' in small lumps of unspecified size made by the native crucible process in the 'Deccan'. The famed Damascus swords were made from this Indian steel, deemed then a high technology and advanced material. The inspiring question is, what can we attempt today in the field of advanced materials that will match the fabulous Wootz steel record?!

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1

Advanced Materials: National Priorities

Preamble

Materials figure ubiquitously as an enabling parameter in nearly every system associated with modern technologies encountered in a wide spectrum of sectors like heavy engineering, transportation, aerospace, power generation, microelectronics and bioengineering. In each of these sectors progress has been aided by a continuous development of advanced materials with improved performance capabilities. Invariably the shaping of these materials, in the form of components or devices under production conditions, and for actual use in systems concerned, has necessitated development of new, and often expensive and complicated, processing methods. The total scenario is thus quite mind-boggling in terms of the bewildering variety of basic materials, their combinations, the demands made by the advanced systems in different disciplines and related processing and manufacturing technologies. On the other hand, the scenario is fascinating because of the potential role of scientific inputs in materials development, the revelation of the commonality of concepts that underlie seemingly diverse materials (leading to substitution for conservation of materials, e.g. plastics in place of wood for packaging and cotton for fabrics, optical fibres for copper cables in communications), the challenge to innovative processing methods and the need to generate new design methodologies.

The growing awareness of the importance of materials development is reflected in a number of initiatives launched by government policy making bodies in advanced countries. In this context the advanced materials programme for our country should be formulated keeping clearly in mind not only the future material needs of our technologies but also the national resources position, the indigenous situation in the area of materials processing, a near lack of sophisticated manufacturing infrastructure and the constraints imposed by the funds position. Thus arises a paramount need for selecting a few advanced materials for concentrated research and development. An attempt is made here to suggest such a selection and indicate an approach to further action.

The approach to selection and further action requires an assessment of the status of advanced materials internationally and in India. Accordingly a brief review of worldwide and indigenous developments in selected new materials is presented in this report. Prominent areas for further fruitful research become thus apparent with regard to superconducting and structural ceramics, new polymeric materials such as polymer blends and molecular composites, metallic alloys like aluminium-lithium for higher specific stiffness, high fracture toughness steels, separation of rare-earth metals and development of rare-earth element bearing alloys and metal-matrix composites. It is noted that in regard to high temperature superconductors a national programme has been recently launched with an apex body chaired by the Prime Minister, a National Programme Management Board and a substantial allocation of funds. In the field of new materials, this is perhaps the first such initiative to have been taken at the highest level. While it is necessary to be selective in drawing up research programmes, deliberate choices become even more essential when it comes to developmental efforts. The report makes specific recommendations for undertaking major and comprehensive product development programmes in different groups of materials, namely titanium (metallic materials), silicon based microelectronics and III-V semiconductor compounds (electronic materials), neodymium-iron-boron (magnetic materials), zirconia (ceramics) and çarbon, silicon carbide, kevlar fibres and carbon composities (composites).

It clearly emerges that there is a need to have a body at the national level to launch, coordinate, review and monitor programmes in the area of advanced materials. Such a body can be called National

Advanced Materials Research and Development Board. Only such a body can have the necessary knowledge of, and authority to mobilise, the existing capabilities and recommend installation of additional facilities. The research areas and the list of materials for integrated development suggested in this report can be reviewed by such a National Board which may then develop appropriate strategies for accomplishment of reaching chosen goals. ■

1 Review of Status of Selected Advanced Materials - General

1.1 Non-Load Bearing Materials

1.1a Electronic Materials

Crystalline silicon forms the rockbed of semiconductor electronics today. It will remain so in the coming decade in computer related applications involving data and signal processing through digital integrated circuits. The trend has been, and will continue to be, to increase the density of circuit functions on a chip so as to enable ever enhancing capability. In the present very large scale integrated (VLSI) circuit era we are dealing with micron and submicron feature sizes and a capacity of 256 KB static random access memory (SRAM). In the next few years 1MB SRAM requiring a feature size in the range 0.5 to 0.7 μm will be available. Recent improvements in optical lithography will reduce the feature size to 0.3 μm by 1995. Beyond 1995, even smaller feature sizes can be expected with the advent of electron beam, ion beam and radiation lithographic techniques. Silicon on insulator (SOI) technology will remove the limitations due to bulk silicon and can result in 16 MB SRAM chips in the years beyond 2000.

Molecular beam epitaxy (MBE) is another technology which holds great promise for controlled deposition of submicron structures. Semiconducting compounds of Group III and V of the Periodic Table, such as GaAs, InP are next in importance only to that of silicon in view of the unique properties of these compounds such as direct band gap, ability to form ternary and quaternary alloys, low effective mass and consequently higher electronic mobility and the possibility of growing semi-insulating crystals which provide ideal substrates for monolithic microwave integrated circuits (MMICs). Moreover, the processing of these materials offers a wider technological choice than is possible with silicon. The wider choice of material properties together with sophisticated processing technologies like molecular beam epitaxy (MBE), metalorganic chemical vapour deposition (MOCVD) or its variants like chemical beam epitaxy (CBE) or meta organic ion-beam epitaxy (MOMBE) have made it possible to artificially grow-structured lattices which exhibit quantum phenomena on a macroscopic scale.

However, high cost and low density of devices on a chip because of yield constraints (arising from the fact that thermal stress induced dislocation density is considerably higher in GaAs as compared to silicon) has led to restricted use of GaAs in digital circuits. But, in the area of data acquisition and communication and optoelectronic devices, GaAs technology has indeed ushered in a revolution. The potential application areas for GaAs include its use as a front end signal processor in military applications like radar and on-board processors, as low noise amplifiers in the area of microwave, MMIC digital phase shifter for phased array radars, in electronic warfare systems and in optoelectronic systems like fibre optics and light emitting diodes (Ga In As P).

In the area of slow electronic devices, amorphous silicon will play an important role and will replace selenium in reprographic and photovoltaic applications. Semiconductors based on zinc and cadmium sulphide will continue to be useful as phosphor materials for television and video terminals.

In the area of electronic communication, optical fibres will largely substitute copper and aluminium wires. The optical fibres will be based largely on transparent silica and to some extent on the recently proven oxide free glass based on heavy metal fluorides.

In the area of superconductors, rapid developments will take place in the synthesis of new high temperature superconductors based on mixed oxides. However, the engineering problem of making these brittle, ceramic superconductors into useful shapes has just begun to be tackled. Within the next decade or so these superconductors should find extensive use.

1.1b Magnetic Materials

In the area of permanent magnetic materials, neodymium-iron-boron (Nd-Fe-B) magnets represent the most exciting prospect for commercial development. Nd-Fe-B magnets exhibit maximum energy product values, more than 10 times that of ferrite (largest tonnage permanent magnet material at present), nearly 10 times that of Alnico and more than twice that of samarium-cobalt magnets. Production of Nd-Fe-B on tonnage basis has been achieved by the Japanese and the Chinese using the powder metallurgy route. Use of rapid solidification technique for producing Nd-Fe-B magnets with enhanced magnetic properties is under intensive study in the various laboratories of USA, Japan and Europe. It is expected that Nd-Fe-B will largely replace Alnico and samarium-cobalt magnets by the end of the century. If the price of Nd-Fe-B can be brought down significantly by economies of scale and other means and its high temperature capability raised, Nd-Fe-B magnets hold the promise of replacing ferrites.

1.1c Oxidic and Other Single Crystalline Materials

Several advanced novel materials in single crystal form are finding critical application as a result of their opto-electronic, ferroelectric and piezoelectric characteristics. Examples are Nd doped YAG single crystals, lithium niobate (LN), lead zirconate titanate (PZT), potassium dihydrogen phosphate (KDP). These materials find numerous applications in lasers, signal generation, signal modulation, signal conversion and in general control electronics. Neodymium doped crystals of garnet structure such as YAG for solid state lasers and single crystalline $LiNbO_3$ as opto-electronic material are needed in significant quantities. The sizes of the crystals needed are both small and big. They are almost entirely imported.

In the important field of acousto-optic and electro-optic materials a major effort is currently underway in USA and USSR for development of lead halide crystals (e.g. $PbBr_2$) and thallium selenide crystals (e.g. Tl_3 As Se_3) with much higher figure of merit than $LiNbO_3$ and superior non-linear characteristics (higher efficiency of generation of harmonics) which will then render them good candidate materials for use in Bragg cells and image recorders. The problem here is to understand the underlying science and exercise great control over solidification processes to achieve growth of crystals from liquids with appropriate microstructures.

1.2 Load Bearing Materials

1.2a Metals and Alloys

In the developed countries the spurt in demand for advanced metallic materials is unabated in contrast to the saturation of demand in the case of primary metals such as steel and aluminium. (The steel situation has not been further discussed in this report as the Science Advisory Group headed by Dr V S Arunachalam has recently prepared a report on new initiatives for the consideration of the Ministry of Steel and Mines). Titanium represents an advanced metallic material whose potential has not yet been comprehensively realised. Titanium and its alloys have an unusual combination of light weight, high strength, high toughness, corrosion and erosion resistance and non magnetic characteristics. This material has already proven indispensable in the power sector, chemical and aerospace industry and defence sector. The demand for titanium and its alloys can be expected to increase in the coming decades.

Only five countries in the world (USSR, Japan, USA, UK and China) have full-fledged facilities for the extraction of titanium metal. However, since titanium and its alloys are very reactive, special processing facilities for melting, casting and welding have been developed over the last two decades. In the coming decades, titanium and its alloys will no longer be considered exotic and will find wider applications as engineering materials with an unusual combination of properties.

Magnesium (density 1/3 that of titanium) and lithium (density 1/8 that of titanium) are the other two metals of the family of light reactive metals which are gaining in importance worldwide. Lithium, the lightest among metals with specific gravity of 0.5 g/cc, may legitimately be termed the metal of the future. Not many years ago lithium was considered an atomic energy metal useful mainly for the production of tritium required for fusion energy experiments. The usefulness of lithium in the field of aluminium extraction (in the form of lithium carbonate addition to the electrolytic bath), in batteries and medicine is well-known. With these application areas and the advent during the recent years of a range of damage tolerant, medium and high strength Al-Li alloys for aeronautical applications and light weight Mg-Li alloys for space applications, there is a dramatic growth in the demand for this highly reactive metal. Production of lithium metal, which is currently around 6000 TPY, is expected to increase to a phenomenal figure of a few lakh tonnes per annum by the year 2000.

Among the newer metals particular mention needs to be made of the group of rare-earth elements whose value has received a further massive boost with the advent of high temperature superconductors.

Among light alloys, aluminium-lithium alloys are proving to be the most important in Al-alloys development. These alloys have the highest specific stiffness among aluminium alloys. The ingot and the RSP (rapid solidification processing) are the two routes now under investigation for their manufacture. The ingot route currently seems successful as it is amenable to making the alloy inbulk and at lower prices. However, in the coming decades, RSP may emerge as the process route since it has the potential to develop Al-Li alloys with higher lithium levels than possible by the ingot route. Large scale production of Al-Li alloys by the ingot route has already commenced in countries like USA and UK. Over the next 10 to 15 years these alloys should see extensive use as aerospace structures and in portable bridges and also in the transportation sector.

In the area of advanced materials for gas turbine engines for aircraft, single crystal superalloys, ordered intermetallic alloys based on titanium and nickel aluminides and mechanically alloyed dispersion strengthened superalloys have captured world attention. It is important to note that in the above cases, R&D has been towards not only alloy development but also process development. For example, completely new processing technologies like single crystal growth techniques, mechanical alloying on tonnage basis, superplastic and isothermal forging, atomisation and hot isostatic pressing have been developed in order to process these alloys. While single crystal superalloys are already in service as turbine blade materials in the latest aircraft engines, dispersion strengthened alloys and titanium aluminides promise to find application as turbine disc and compressor materials respectively within the next decade.

1.2b Ceramics

Ceramics materials are the strongest as well as the stiffest solids. However, they are brittle. A great deal of research in recent years has been aimed at overcoming brittleness, so that ceramics are rendered more easily processable and reliable in load bearing applications. The result is a continuous improvement in the toughness of ceramics. For instance, during the last one decade, the fracture toughness of zirconia has been raised from 8 to 20 $MPa\sqrt{m}$. In the light of this development, a number of ceramic materials are being thought of for the first time for engineering (structural) applications.

Silicon carbide (SiC), silicon nitride (SiN), zirconia and sialon represent the important engineering ceramics under development. Partially stabilized zirconia (PSZ) (a new variation of the widely used zirconia formed by adding Y_2O_3 or MgO in quantities sufficient to stabilise the high temperature cubic phase) is already being used as dies in hot extrusion processes with demonstrated advantages of long maintenance-free life and better surface finish for the product. Zirconia toughened alumina ceramics are promising tool materials. Fully stabilized zirconia is currently under development for thermal barrier coatings on gas turbine engine components. However, the potential application of economic impact for engineering ceramics will be as cylinder liners, piston caps, valve guide seats etc. in the adiabatic engine for automobiles. Ceramic materials like silicon nitride may also serve aircraft engine applications in the years beyond 2000.

1.2c Polymers

'Polymers' is a generic term which includes a whole host of product forms like plastics, rubbers, fibres, sealants and adhesives. The light weight and the ease of processing polymers has made them increasingly more competitive against metallic materials.

Among the polymers, plastics can be broadly classified into low value commodity plastics (such as polyethylene (LDPE); polyvinyl chloride (PVC); medium value engineering plastics (like polyacetals, polycarbonate) and high value speciality plastics (e.g PVDF, PEEK, PPS). Apart from the conventional uses such as milk pouches (LDPE), woven sacks for fertilisers (PP or HDPE) and bottles (PVC), commodity plastics are finding applications in entirely new areas. Geotextiles for example help in drainage, stabilisation and erosion control. Similarly industrial fabrics such as coated fabrics and filtration fabrics have been developed. In the area of agriculture the use of plastics can help conserve water in canals and in the agricultural field. Engineering plastics offer many advantages and have replaced brass and zinc in pump impellers, stainless steel in conveyor links, steel in gear pumps and ball bearing, and glass in street light and sign boards. Speciality plastics have found use as transducers, broadband thermal and sonar detectors, bolometers, medical diagnostic equipment and as micro electronic components.

Polymer fibres can be classified as commodity fibres and speciality fibres. Commodity fibres include polyester fibres (for fabrics), polyamide fibres (for apparel wear) and acrylic fibres. Kevlar, which surpasses steel in terms of specific strength, is a striking example of a mature speciality fibre. Gel spun fibres, based on ultra high molecular weight, high density polyethylene, which excel Kevlar, have been recently developed.

Effect polymers are materials whose use imparts major improvements or results in substantial economic benefits. For example, oil soluble drag reducing polymers, when added to the oil in minute quantities, enhance the crude oil through-put in a pipeline. Other examples are the superabsorbing polymers which enhance agricultural productivity, use of membranes instead of energy intensive gas separations in industries and controlled release polymers which reduce toxicity in drugs, pollution in pesticide industries and wastage in fertiliser industries.

1.2d Composites

Composites can be broadly classified as polymeric-metal and ceramic-matrix composites. High performance polymer composites are made by using strong and stiff fibres (carbon, boron, aramid) held in desired orientation, and bound with suitable thermoplastic and thermoset matrix materials. At present combat aircraft use close to 30% composites and this will go upto 50% in the future generation combat aircraft. Helicopters also make use of polymer composites as structural materials. Composites such as carbon/epoxy hold great promise in the manufacture of industrial machinery as reciprocating or rotating parts. Composites based on high specific strength fibre kevlar are already displacing aluminium alloys for aircraft frame applications. At present these composites are being used in helmets, body armour, movable bridges and mobile rocket launchers mainly on the basis of performance rather than cost. Newer and wider applications are envisaged in the coming decades.

Metal- matrix composites (MMC) represent a new class of engineering materials for which the future is very bright. These are usually fibre-reinforced composite materials where the matrix can be any of the well known metallic materials (titanium, aluminium, superalloys etc) and the reinforcing fibre can be boron, silicon carbide (SiC), refractory metal, graphite or boron carbide. Compared to polymer composites, the MMCs have superior high temperature capabilities. MMCs have already found application in pistons of turbo diesel engines (Al_2O_3 - SiO_2 - Al), diesel engines (SiC-Al) space shuttles (B-Al, Gr/Al) and in fighter aircraft (SiC-Al). In the coming decade, their use will expand considerably with possibilities of being used in space structures, fan compressors, turbine blades and vanes, landing gears etc.

In a manner similar to MMCs, ceramic-matrix composites (CMC) represent a new class of materials, most promising for heat engines and other high performance applications. CMCs usually consist of a basic ceramic matrix, such as borosilicate glass, silicon carbide (SiC), silicon nitride (SiN), aluminium oxide (Al_2O_3) or mullite (a complex compound of Al, Si and O) reinforced by ceramic fibres, whiskers or particulates. The ceramic matrix gives composites greater temperature resistance and the fibres block the growth of cracks by deflecting the crack or pulling the fibre from the matrix. Both the processes absorb energy and slow down the crack growth. In comparison to ceramics, even if the matrix becomes riddled with cracks, a CMC will fracture less readily than an unreinforced ceramic because of the many fibres bridging the cracks. In the coming years, CMCs are expected to find widespread application as structural materials for use upto 2200°C and in reciprocating engines operating at low temperatures.

2 Review of Status of Advanced Materials Research - India

2.1 Non-Load Bearing Materials

2.1a Electronic Materials

Semiconductor Materials In India, the main integrated circuit facility based on silicon is at Semiconductor Complex Limited (SCL), Chandigarh. The present feature size is around 5 μm and will decrease to 1 μm in the near future. Thus, our capability is upto LSI. Recently, major facilities like silicon MBE, reduced vapour phase epitaxy and electron beam lithography have been set up within DRDO. With the installation of these facilities, submicron feature sizes will be possible in the near future. Mettur Chemicals have set up a plant to produce electronic grade silicon. The purity and the cost of Si obtained from this company, and use of this silicon for photo-voltaic applications (solar cells), are being examined.

Work in the area of semi-conductor III-V compounds is confined to a few laboratories. A major programme in this area is being carried out at Solid State Physics Laboratory (SPL) - where facilities for synthesis and growth of single crystals, epitaxial processing facilities like molecular beam epitaxy (MBE) and metalorganic chemical vapour deposition (MOCVD) for GaAs devices including ion implantation, electron beam micro fabrication (EBMF) and Plasma CVD have been established. Work has been initiated on devices such as Gunn diodes, Millimeter wave devices and MMICs. The facilities are being expanded to cater for newer devices such as HEMT (high electron mobility transistors) and InGaAs devices. Several sophisticated diagnostic facilities like EPMA, SIMS, SEM, DLTS, (deep level transient spectroscopy) have been installed. SPL has recently taken the challenging initiative of setting up India's first (and an advanced production size) crystal growth system, thereby becoming the country's pioneering wafer/device fabricator. Another place where substantial work is being done is at Central Electrical and Electronics Research Institute (CEERI), Pilani where the emphasis is on device design and development.

The only other place (apart from Tata Institute of Fundamental Research (TIFR), Bombay where the emphasis is on theoretical and basic studies) where substantial work is being done is at Indian Institute of Technology (IIT), Kharagpur, which is engaged in liquid phase epitaxy (LPE) studies on InP. As regards work on raw materials, India is a potential major source of gallium in the world as this is a by-product of aluminium production from bauxite and, in terms of contained gallium, Indian bauxite is among the best in the world. At present no major recovery of gallium as a by-product during aluminium extraction is being done. Central Electrochemical Research Institute (CECRI) and Bhabha Atomic Research Centre (BARC) have developed processes for gallium recovery which have been respectively adopted by Madras Aluminium Company (MALCO) and Hindustan Aluminium Company (HINDALCO). Nuclear Fuel Complex (NFC) have established purification techniques to produce 4-6N electronic grade gallium. The suitability of these materials, required for semiconducting applications, is being evaluated. No major effort on synthesis of metalorganic compounds like the group IV alkyls is underway in the country, except for a project on trimethyl gallium at Defence Science Centre (DSC), Delhi. As the success of MOCVD technology ultimately depends upon the availability of high purity metal alkyls, it is necessary to intensify work in this area.

Optical Fibre Materials The present status of optical fibre and cables in the country is that two collaborations have been entered into, one by Madhya Pradesh State Electronics Development Corporation (MPSEDC) and another by Hindustan Cables Limited (HCL). Each will have production equipment to draw optical fibre from preforms made by using MCVD (modified chemical vapour deposition) technology. The optical fibre is being made basically for 1300 nm (1.3 μm) transmission and can be used also for 1550 nm (1.55 μm) transmission. The basic technology for dispersion shifted fibre at 1550 nm (1.55 μm) transmission would also be available. With synchronous transmission and WDM (Wavelength Division Multiplex) techniques, the traffic handling capacity of these optical fibres can be substantially increased.

Optical fibre cable requires specialised materials, other than the cable materials, which have a substantial impact on the total cost. For example, the drawing speed of optical fibre is today dependent on the curing time of the coating material. If this curing time could be reduced by 50%, the same process and equipment would produce double the length of the optical fibre. To prevent optical fibre cable getting damaged due to lightning strikes, the cable has to use nonmetallic strengthening materials. At present these are imported. These are areas of industrial secrets in which India is yet to acquire self-reliance. Therefore, when materials required for optical fibre cable are considered, attention should not be confined to the optical fibre alone but must encompass, as a system, several types of materials needed to make the industrial cable. While the low loss optical fibre suitable for higher wave length (i.e greater than 2000 nm) has not been considered on industrial priority, it is worthwhile pursuing their development in R&D laboratories to meet small length requirements used in instruments and as sensors.

Other Materials for the Electronics Industry The situation with regard to phosphors for the TV industry deserves to be pointed out. All our requirements at present are met through imports.

Hyderabad Science Society has recently prepared a report on sensors which may be referred to (via Department of Science and Technology

New Delhi) for the current status in India in the field of sensor materials.

In regard to ceramic superconductors, significant activity is presently underway at Indian Institute of Science (IISc), Indian Institute of Tropical Meteorology (IITM), TIFR and national laboratories like National Physics Laboratory (NPL) and BARC. The engineering problem of making these superconductors into useful forms is, however, yet to be comprehensively overcome.

2.1 b Magnetic Materials

Defence Metallurgical Research Laboratory (DMRL), Hyderabad, has undertaken a project on the processing of Nd-Fe-B permanent magnets through both powder as well as RSP routes. Extraction of Nd is also being experimented with on a laboratory scale. Considering the fact that India has enormous resources of Nd containing monazite ore, and, in contrast, absolutely no mineral resources of nickel and cobalt, extensively used currently in Alnico magnetic alloys, the present Indian status of R&D in the case of Fe-Nd-B alloys needs to be stepped up.

2.1 c Oxidic and Other Single Crystalline Materials

At present laboratory scale facilities for growing some of the crystals and their characterisation exist at IISc, BARC and Anna University. The facilities set up at SPL and Defence Science Centre (DSC) (both of Defence Research and Development Organisation) are quite considerable and can be regarded as suitable for pilot scale production of YAG and GaAs crystals. Production of silicon crystals is underway at Super Semiconductors near Calcutta, Silitronics, Hosur and at Mettur Chemicals (Metchem), Tamil Nadu. However, for commercial level production of single crystalline materials, an integrated infrastructure does not exist in the country.

2.2 Load Bearing Materials

2.2a Metals and Alloys

Industrial scale plants for beneficiation of titanium deposits and manufacture of $TiCl_4$ have been set up in the country (Kerala and Orissa). A demonstration plant for the extraction of titanium sponge from $TiCl_4$ has been working at DMRL for the past two years. However, no full fledged commercial plant exists for the manufacture of titanium sponge. Advanced processing facilities are available at Midhani, Hyderabad, to melt, cast, forge, roll and draw titanium and its alloys to mill forms. Facilities for making titanium tubes are in the process of being established.

Technology for the extraction of magnesium from sea bitterns was pioneered by the Central Electrochemical Research Institute (CECRI), Karaikudi. Based on this technology a 600 TPY magnesium plant is presently under establishment at Valinokkam in Tamil Nadu. This plant is expected to go on stream by end 1989. The process involves production of anhydrous magnesium chloride from sea bitterns followed by fused salt electrolysis. The National Metallurgical Laboratory (NML), Jamshedpur had also, for several years, operated a pilot plant for the production of magnesium metal by the "Pidgeon" process involving ferro-silicon reduction of calcined dolomite. Recently this technology has been transferred to the Andhra Pradesh Industrial Development Corporation who intend to promote a second 600 TPY plant in Andhra Pradesh based on this process. At DMRL, a facility for the production of magnesium metal by fused salt electrolysis of anhydrous magnesium chloride in 30,000 Amp cells is currently in operation. The technology being developed here will not only facilitate the establishment of a large recycle plant as part of an integrated Titanium Sponge Plant (an essential requirement for the economic production of titanium production) but also become useful for the Tamil Nadu Plant under installation. Insofar as magnesium is concerned, it is thus seen that steps needed for technology development and commercial production have already been taken and, with increase in demand, an enhanced capacity should be available automatically.

The only industrial process for the production of lithium metal is fused salt electrolysis of anhydrous lithium chloride in LiCl + KCl bath. Considering the highly reactive nature of the metal, and associated fire and explosion hazards, the technology for the production of this metal in a pure form is quite complex and involved. BARC initiated a laboratory programme on lithium extraction by fused salt electrolysis. DMRL, in collaboration with BARC, has recently established a cell that can produce upto 1 kg per day of pure lithium metal. DMRL plans to upgrade this technology gradually and establish facilities for the production of 1 tonne per annum pure lithium metal.

Indian Rare Earths Limited (IRE) is the only company in India that is processing monozite for the production of thorium and rare earth concentrates. Currently IRE is processing around 4,000 TPY of monozite and, with the commissioning of a new plant in Orissa, this will go up to 8,000 TPY.

Complexities of separation technologies have hitherto come in the way of producing high purity individual rare earths in tonnage quantities and, as a result, the bulk of the rare earths exports are in the mixed chloride form. More recently, however, facilities have been set up to produce some rare earth concentrates on a moderate scale (60% in yttrium, 60-70% in samarium etc.) and, on a still smaller scale, purer individual oxides. While certain solvent extraction and ion exchange techniques have been evolved for rare earths separation, there is a need to intensify our efforts in this direction so that large scale separation plants for the production of individual rare earths of high purity can be established. This will not only meet the indigenous demand but also encourage exports, in a highly value added form, thus exploiting the extraordinary mineral wealth of our country to the fullest extent.

At DMRL, development of Al-Li alloys by both ingot and RSP route is under progress. Although there is a large production base for aluminium and its alloys in India, no facility exists in the country for the production and processing of aircraft grade aluminium alloys. The opportunity provided by the newest class of high specific stiffness Al-Li alloys should be seized to develop, within the country, production activity in the important field of aircraft structural alloys.

In the area of advanced materials for gas turbines, the major development work has been carried out at DMRL. Work in the area of nickel and titanium aluminides has been recently initiated at DMRL. However, industrial scale production of these materials is not yet possible. In the case of wrought superalloys, Midhani has the facility to make them on a tonnage basis.

2.2b Ceramics

In the areas of engineering ceramics, the development activity in our country is not sizeable. Laboratory scale development of toughened zirconia (PSZ) and SiN is being done at DMRL and Central Glass and Ceramic Research Institute (CGCRI), Calcutta, respectively.

2.2c Polymers

Industrial production of high volume, low value commodity plastics is well developed in the country. Important commodity plastics like LDPE, HDPE, PVC, PP, ABS and LLDPE are being manufactured in the country and have found extensive applications. However, the demand for these plastics for agricultural applications (water conservation, canal lining and drip culture) are steadily gaining acceptance. In the area of engineering plastics and speciality polymers, India's industry is yet to make a mark. Geotextiles and industrial fabrics, based on these commodity plastics, like multilayer extrusion of films, multi-layer blow moulding and profile extrusion are yet to be introduced in India.

We are here concerned with engineering materials and in this context it is appropriate to discuss engineering plastics a little further. The exploitation level of the engineering plastics in India is very poor. Such a state of affairs is due to (a) inadequacy of R&D effort on material development; (b) non-availability of sophisticated and automated processing equipment; (c) lack of appropriate tools for design and manufacture; and (d) consumer resistance. At present, engineering plastics being manufactured in India include polyethylene terephthalate (PET), polybutylene terephthalate (PBT), nylon, acrylonitrile butadiene styrene (ABS). However, even these plastics have not been exploited to the full. Other important engineering plastics such as polycarbonate, polyacetal, polyphenylene oxides are important examples of engineering plastics which are yet to be manufactured in India, although the use of imported grades of these materials in special applications is growing. In a noteworthy move Indian Petrochemical Limited (IPCL) have very recently entered into collaboration with General Electric (GE) of USA for the establishment of an Applications Development Centre which will cater for selected engineering plastics including polycarbonate. No concerted effort has been made either to develop or manufacture speciality plastics, noteworthy of which are polyimides and polyether ether ketone (PEEK). In the area of polyester fibres, India already has a sophisticated industrial infrastructure for large scale manufacture. However, there is a real need to develop and produce fibres which are ideally suited for the tropical climate of our country.

In the area of speciality fibres, India notably lags behind. This is a critical situation since the indigenous development and manufacture of composites is heavily dependent on self-reliant technologies. National Aeronautical Laboratory (NAL) has recently developed Kevlar 49 type aramid fibres in small quantities. Efforts are underway to develop quality control methods to get continuous fibres of consistent strength and modulus and also for up-scaling the process with the help of Shriram Fibres in the private industry. In the area of carbon fibre technology, IPCL has recently negotiated the purchase of technology pertaining to the manufacture of high modulus carbon fibres based on polyacrylonitrile (PAN) precursors. Essentially no expertise exists in the country with regard to effect polymers.

2.2d Composites

Composites are materials excellently suited to the Indian situation because of abundantly available raw materials like glass, polyester, rice husk and pitch and because the processing of composites is labour intensive. Expertise in the area of conventional composites such as fibre reinforced plastics (FRP) exists in the country. The present production of glass fibres (the most common fibre in FRP) in the country is about 25 tonnes per annum, which incidentally is less than

3% of world production. Considerable development work in the area of resin-matrix composites has been carried out at NAL, Aeronautical Development Establishment (ADE) and DRDL. The complete design and fabrication of the rudder for the MiG aircraft, done at NAL, has been succesfully static tested and accepted by Hindustan Aeronautics Limited (HAL). Another rudder for the Dornier aircraft is presently undergoing similar development at NAL which has also assembled a complete FRP aircraft and is in the process of designing another.

Efforts for the development of high performance composites have jus begun. For example, a technology centre has been set up recently a Defence Research and Development Laboratory (DRDL), Hyderabad, for the manufacture of carbon-polymer matrix and carbon-carbon composites. Plans are underway for the manufacture of coal tar pitch required for C-C composites at the Indian Institute of Chemical Technology (IICT), Hyderabad, (500 kg. per batch). However, no comparable effort has been made in the country with regard to Kevlar fibre reinforced plastics.

In the area of MMCs (Al-SiC) and CMCs (Al_2O_3-SiC) laboratory level experiments are underway at DMRL. However, the manufacture of SiC fibres and whiskers is yet to begin in the country.

Academic research in the area of composites is largely carried out in institutions like the Indian Institutes of Technology at Madras, Kanpur and Bombay, IISc., and national laboratories like NAL, NPL and Defence Materials Stores Research and Development Establishment (DMSRDE).

3 Technologies for Materials Processing

Development, production and ultimate use of materials involves several stages. Discovery of a new material and understanding of novel materials requires creative research endeavours in a variety of disciplines: solid-state physics, solid-state chemistry and materials science to name a few. The discovery of mixed oxide super conductors is the latest instance of such an interdisciplinary research effort. However, the actual application of a material as a device, component or a structure requires the development and adoption of processing technologies without which a material with unusual properties may actually remain just a curiosity. Current worldwide effort to develop appropriate processing technologies for converting brittle ceramic oxides into shapes for service applications without deterioration in superconducting properties, associated with the original materials, illustrates the need for technologies in materials processing.

Such processing technologies have not only to be amenable to shaping the material into the required form without deterioration of its intrinsic physical, chemical and mechanical properties, but also be amenable to large scale and often cost-effective manufacturing.

Nowhere is the significance of processing methods better illustrated than in the development of aircraft gas turbine engine components. *Fig. 1* clearly shows that while the early alloys in the jet engine were

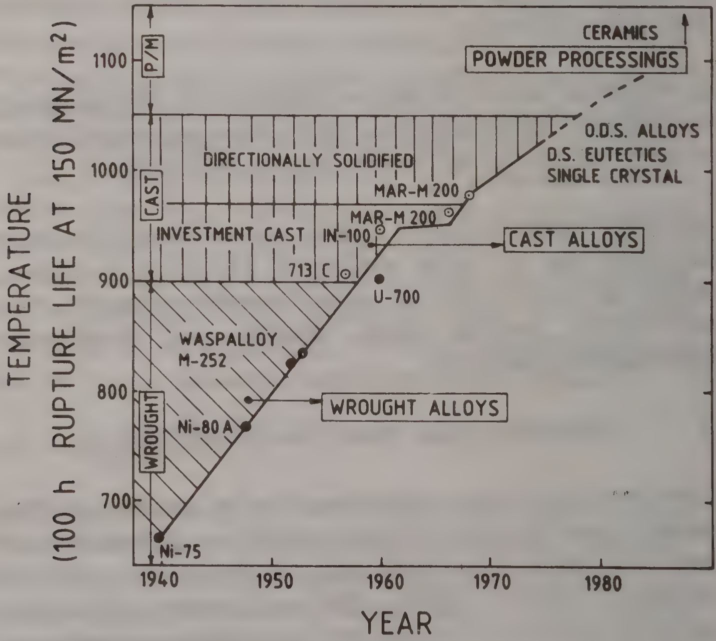


Fig. 1 Development of superalloys for the gas turbine engine.

made by wrought processes (e.g. hot forging), the subsequent ones, because of complex chemistries, involving sometimes more than ten elements in a single alloy, have had to be cast to the required dimensions and shape (e.g. investment casting). The understanding of the requirement of size and shape of internal grains and the solidification process itself led later to directional solidification and growth of single crystals. Application of such processing resulted in improved performance not originally observed in the same alloy. It was further realised that incorporation of carefully designed cooling channels into the turbine components (blades and vanes) could permit still higher gas inlet temperatures. The materials engineer has had then to devise processing techniques (the advent of ceramic cores in castings) to produce directionally solidified or single crystalline complex superalloy blades and vanes with intricate cooling channels. With these developments in the design of the turbine components, which were successfully realised through innovative processing techniques, the permissible gas inlet temperature could be raised from 900ºC to more than 1300ºC without a significant change in alloy chemistry. Currently, in regard to intermetallics or ceramics, newer processing technologies, involving powder metallurgy techniques, are being attempted. The gas turbine engine development thus reflects a stunning saga of growth not only in the types of materials but also in their processing technologies, particularly the near-net shape processing which is becoming more and more widely adopted. It is fascinating to mention that processing methods altering the material's themselves have come to be developed. Notable examples are rapid solidification leading to the formation of amorphous metals, evaporation and fine particle condensation techniques resulting in nanocrystalline metals and injection of accelerated ions (10-500 keV) into solid metals leading to a new world of materials with altered near surface properties. *Figure 2* shows how improved processing technologies have been continuously aiding enhanced performance of the alloy system and how this trend is being maintained despite a fall in consumption of metallic materials.

In the making of single crystalline materials, purity of the feed stock is the driving force in the performance of any electronic device. But for the advent of the purification processes there would actually have been no electronics industry. A variety of methods are now available to purify the raw materials, some of which are zone refining, fractional crystallisation, repeated sublimation, repeated freezing at high G. However, the selection of the purification process depends on the nature of the starting materials. The step that follows the purification process is the growth of the crystal. The crystals can be grown either from the melt, the vapour or the liquid. In regard to growth from melt, the material solidifies under conditions of negligible nucleation rate and high growth rate. A single crystal then grows and the entire material is transformed to a single crystal. Continuous growth of single crystals requires very little supercooling and the absence of heterogeneous nucleants. These two basic requirements are best met in the Czochralski method (*Fig. 3*). Another popular crystal growing method employs the Bridgman technique. Other crystal growing methods from the melt include floating zone technique, zone-melting and travelling solvent technique.

When crystals are grown from the vapour phase, the vapour may be

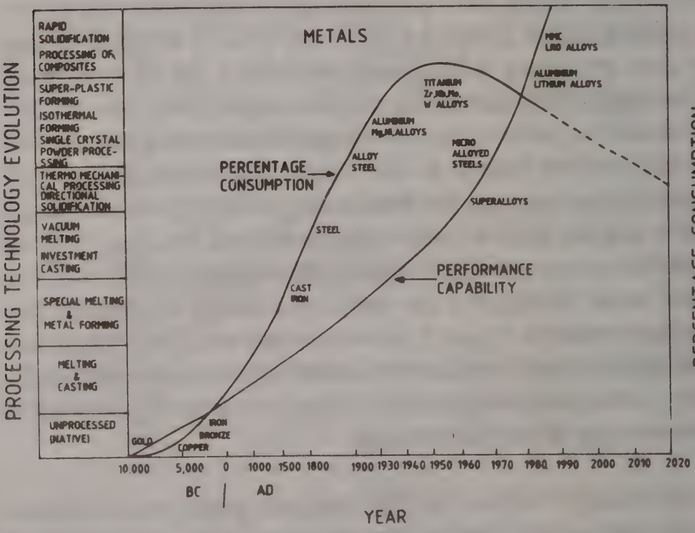


Fig. 2 Evolution of metals.

composed of metal atoms or a volatile compound (usually a halide) of the semiconductor metal which is deposited or decomposed on a seed crystal. Compound semiconductors may be made by mixing the vapours of the two constituents and regulating the partial pressures. CdS and CdSe crystals are grown in this manner. Some of the commonly used methods to grow a crystal from the vapour phase are physical vapour deposition (PVD), chemical vapour deposition (CVD), metallorganic chemical vapour deposition (MOCVD), vapour epitaxy (VPE) and semiclosed vapour phase epitaxy (SVPE).

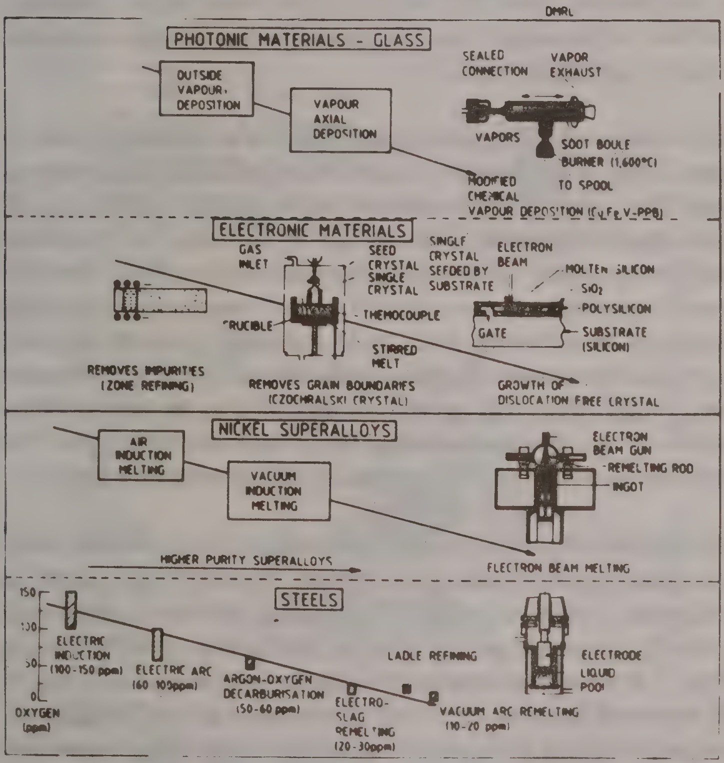


Fig. 3 Illustration of the progress in purification technologies for producing advanced materials of high performance capability.

Once the crystal is grown, it is subjected to a number of characterisation processes, namely optical characterisation (measurement of refractive index), laser treatment (to check damage threshold), impurity identification etc. The orientation and general crystalline perfection are checked by Laue X-ray diffraction. Optical properties are evaluated by measuring transparency (typically at 1.16 μm) and transmittance measured using IR-spectrophotometers. The carrier density and mobility are measured by Hall effect and resistivity evaluation. After the crystal is characterised, it is sliced and polished to make wafers and other forms and they then become ready for processing into a device or component. As an essential requirement of the advanced materials capability, India should set up integrated facilities for the manufacture and characterisation of single crystalline materials and components.

Purification technology plays a prominent role in the development of glass fibres. In fact, one of the most important advances in making glass fibre has been the invention of ways to make a preform out of glass of ultra-high purity. Three competing methods (Fig. 3): outside vapour deposition, vapour axial deposition and modified chemical vapour deposition are now currently in use. These methods allow the profile of the refractive index to be controlled precisely. In each method a vapour made of a halide of silicon, such as $SiCl_4$, is directed onto or into a glass rod, and silica is deposited on the outer or inner surface of the rod when the vapour reacts with water or oxygen. The three methods have all been adopted in various production facilities.

Purification technologies are not exclusive to electronic and photonic materials. Improved melting and refining techniques have played a major part in the development of nickel alloys and special steels with markedly improved performance in high technology applications (Fig. 3). For instance reduction in oxide and sulphide contents results in improved ductility. Improved cleanliness has similar effect on properties in other alloys as well. It is now established that transverse properties of aluminium alloys are enhanced through reduction of impurity content, especially iron, which is to be particularly noted in India as indigenous aluminium invariably has a relatively higher iron content.

While the development of new materials, which is a result of basic scientific principles at the conceptual stage, cannot be translated into reality without gaining mastery over the related processing, such processing technologies themselves often depend upon the input of good science for successful operation. This idea can be excellently illustrated with the example of cement, which is perhaps the world's largest and most successful material. The primitive Pozzolana cement had very poor flexural strength and possessed extremely low ductility. Later, Portland cement, the most commonly known form of cement, was developed in the middle of the nineteenth century. The flexural strength of this material was about 10 MPa and a fracture energy of

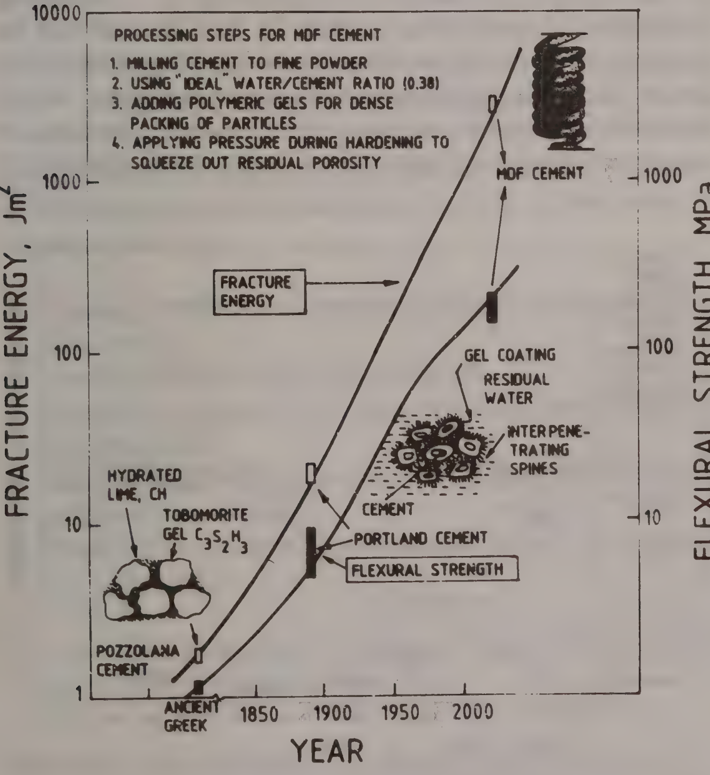


Fig. 4 Progression in the development of ductile cement.

about 20 Jm^{-2}. After a century of this development, we have today what has been termed MDF cement with strength fifteen to twenty times larger (150-200 MPa) and at the same time ductility eight times better (fracture energy -50,000 Jm^{-2}). This dramatic improvement in properties is a result of special processing adopted for MDF cement on the basis of a scientific insight into the structure-property relationship (*Fig .4*). The advent of MDF cement radically widens application areas. A low energy consuming material, that promises to replace plastics and metals in several applications, is now on the anvil.

In a similar manner, the manufacture of otherwise brittle engineering ceramics on a tonnage basis is also closely linked to the development of relatively new processing technologies (*Fig. 5*). The growing consumption of ceramics has undoubtedly been facilitated by the development in ceramic processing. Important developments include powder manufacturing techniques like solgel and freeze drying, preconsolidation by slip casting or injection moulding, consolidation through hot pressing and sintering and finally the development of

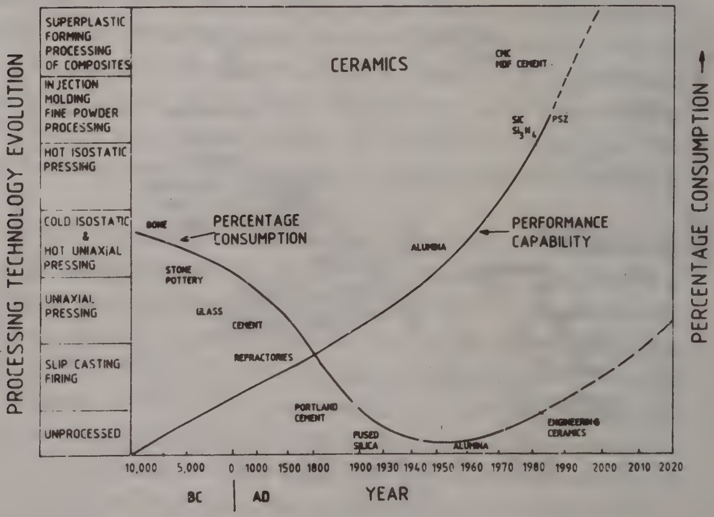


Fig. 5 Evolution of ceramics.

special non-destructive inspection techniques using the acoustic microscope.

Processing technologies hold the same level, if not greater, of significance in the making of polymer products and composites. Appreciation of the importance of processing technologies and manufacturing engineering, which involve considerable financial and organisational inputs, holds the key to indigenous availability of advanced materials in a form ready for industrial use. Equipment manufacture and instrumentation is an essential part of processing and production technologies and far greater attention is needed here than what we have been able to hitherto muster [see the chapter on instrumention (chapter 6) of this volume].

4 Policy Issues Related to Advanced Materials Development

In order to develop a firm technology base for indigenous production of advanced materials, and components based on such materials, the key ingredients are:

- A deliberate decision by a major user agency to adopt the indigenous product.
- A strong and self-confident technical will.
- Cooperative linkages among relevant high technology laboratories/institutions.
- Equipment availability through procurement, indigenous development or manufacture.
- Fiscal measures supportive of indigenous materials development and application.

It is worthwhile illustrating the above key factors with a couple of examples of successful Indian ventures.

Maraging steel is an example of a high technology steel product. This is the highest strength structural steel combining in itself unusually high fracture toughness. The Indian Space Research Organisation

(ISRO) (user agency in this case) made a deliberate decision to use this steel as rocket motor casing for their PSLV rocket. DMRL had a developmental programme for this steel which has, thanks to a collaborative programme with Midhani, grown into a production technology for this steel. The ISRO decision to accept Midhani's steel provided a great stimulus. Midhani joined hands with the Rourkela Steel Plant (RSP) in India and Krupp Company in West Germany and sucessfully met the ISRO requirement for large size plates (with RSP) and rings (with Krupp) for the PSLV programme. The results, in terms of size and weight of the product and its mechanical properties, are such as to place India in the forefront of maraging steel technology (*Fig. 6*).

Another notable example is the indigenous production of zircaloy tubes (*Fig. 7*) for nuclear fuel cladding in Indian power reactors. This constitutes a notable instance of the ore-to-product chain handled all the way exclusively by local effort. The production of high purity zirconium from indigenous raw materials, the processing technology for conversion of the metal into zircaloy, shaping the alloy into tubes

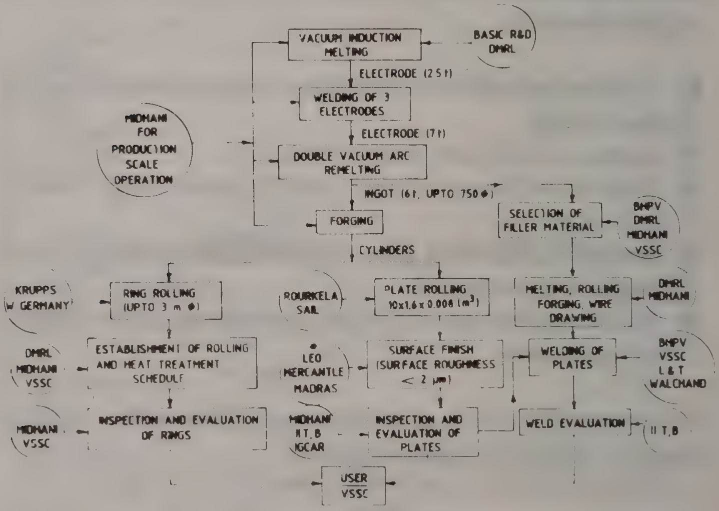

VACUUM INDUCTION MELTING
BASIC R&D DMRL
ELECTRODE (2 5 t)
WELDING OF 3 ELECTRODES
ELECTRODE (7 t)
MIDHANI FOR PRODUCTION SCALE OPERATION
DOUBLE VACUUM ARC REMELTING
INGOT (6 t, UPTO 750 ϕ)
FORGING
SELECTION OF FILLER MATERIAL
BMPV DMRL MIDHANI VSSC
CYLINDERS
KRUPPS W GERMANY
RING ROLLING (UPTO 3 m ϕ)
ROURKELA SAIL
PLATE ROLLING 10x1.6 x 0.008 (m³)
MELTING, ROLLING FORGING, WIRE DRAWING
DMRL MIDHANI
DMRL MIDHANI VSSC
ESTABLISHMENT OF ROLLING AND HEAT TREATMENT SCHEDULE
LEO MERCANTLE MADRAS
SURFACE FINISH (SURFACE ROUGHNESS < 2 μm)
WELDING OF PLATES
BMPV VSSC L & T WALCHAND
MIDHANI VSSC
INSPECTION AND EVALUATION OF RINGS
MIDHANI IIT, B IGCAR
INSPECTION AND EVALUATION OF PLATES
WELD EVALUATION
IIT, B
USER VSSC

Fig. 6 Technology development for and production of maraging steel structures.

of accurate dimensions and appropriate metallurgical texture, and fabrication of the cladded fuel elements have been successfully accomplished by the various agencies (Atomic Minerals Division, Metallurgy Division, BARC; Atomic Fuels Division, BARC; and the Nuclear Fuel Complex).

It has to be appreciated that we are today in a position to visualise such developments in advanced metals because we not only have major laboratories (such as those of the Department of Atomic Energy (DAE), DRDO and Council of Scientific and Industrial Research (CSIR), but also because of the establishment of production facilities at undertakings like Midhani, and NFC. (Please see appendices 2 and 3 for details of the facilities available at Midhani and NFC).

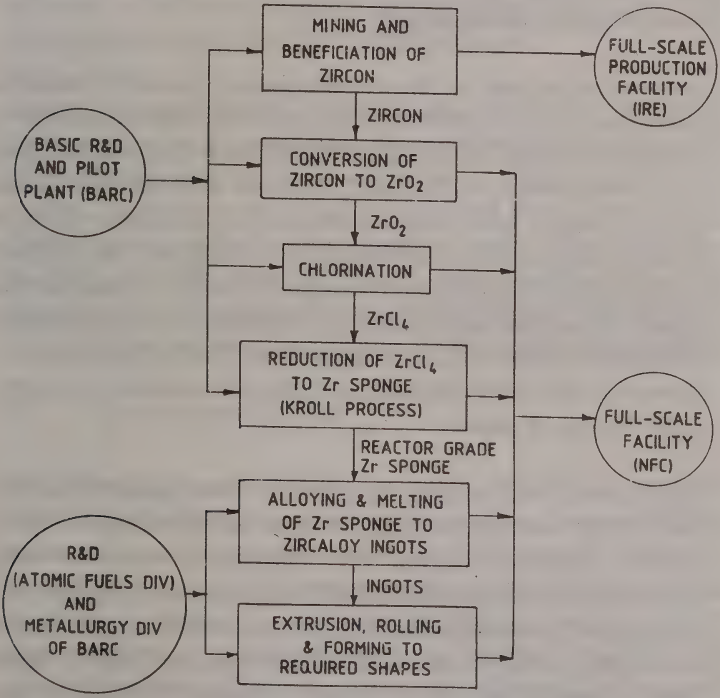

MINING AND BENEFICIATION OF ZIRCON
FULL-SCALE PRODUCTION FACILITY (IRE)
ZIRCON
BASIC R&D AND PILOT PLANT (BARC)
CONVERSION OF ZIRCON TO ZrO_2
ZrO_2
CHLORINATION
$ZrCl_4$
REDUCTION OF $ZrCl_4$ TO Zr SPONGE (KROLL PROCESS)
FULL-SCALE FACILITY (NFC)
REACTOR GRADE Zr SPONGE
ALLOYING & MELTING OF Zr SPONGE TO ZIRCALOY INGOTS
R&D (ATOMIC FUELS DIV) AND METALLURGY DIV OF BARC
INGOTS
EXTRUSION, ROLLING & FORMING TO REQUIRED SHAPES

Fig. 7 Technology development for and production of zircaloy tubes for nuclear fuel cladding.

An equally comprehensive base can be developed in the country in the areas of advanced electronic materials, magnetic materials, single crystalline materials, structural ceramics or advanced composites discussed in the foregoing sections. In the case of YAG crystals, for solid-state lasers, and single crystalline $LiNbO_3$, for opto-electronic applications, the nucleus exists at SPL for comprehensive development. SPL, with advanced facilities for synthesis and growth of single crystals, can play a significant role in the prototype development of YAG and $LiNbO_3$ crystals quite like the role played by DMRL in the case of maraging steels and BARC with respect to zircaloy components. A full fledged production facility for large scale production of $LiNbO_3$ and YAG (like Midhani and NFC) may have to be set up and, more importantly, a user agency (like ISRO for maraging steel and DAE for zircaloy clad fuels) should be identified if production activities have to be stimulated.

Similarly in the area of polymer composites reasonable expertise already exists at the DMSRDE, NAL and NPL. The real need is to pool this expertise to set up pilot plant facilities for polymer composites, to be followed by full fledged production facilities. Full fledged facilities exist in India for the production of commodity plastics. However, the situation is not satisfactory with respect to high performance engineering plastics. Once again, the major constraint is the absence of sophisticated processing machines, lack of consumer awareness and suitable fiscal measures and finally the absence of focus on an application (and user) requiring the use of an engineering plastic in large quantities.

On the basis of the examples given above it is emphasised that if we have to forge ahead in the sphere of these advanced materials in an integrated fashion, i.e. starting from high purity raw materials in the required form, processing the same into appropriate shapes, and to the fabrication of the desired devices and components, the inputs needed have clearly to follow the models briefly described above. These models succeeded because the five key parameters were attended to. It is essential to go about future tasks in an orchestrated fashion, so that no critical element is left out for any reason: technical, financial or relating to policy support. This is the path to follow for expenditious and successful development and production of selected high technical materials. In particular, the question of fiscal measures, mentioned on page 27, will be a key parameter and, therefore, deserves further elaboration.

In order to nurture the growth of a high technology industry and promote exploitation of indigenous products for major national needs as well as for export, innovative materials usage needs to be encouraged through policy measures. Conventional practices in regard to choice of materials should give way to an imaginative approach that allows incorporation of novel materials with improved properties. Attempts to rationalise choice of materials in a variety of situations should receive support. Wherever advanced materials match the national resources position, their utilisation and production should be driven by helpful policy measures and incentives. Stockpiling decisions should become an important policy feature.

It may also be necessary to conceive of a dual policy for pricing products based on advanced materials, as has been done in some of the commercially successful Far Eastern nations. This will provide the needed guarantee to the local industry from the government and inspire the local industry to implement innovative ideas with a view to gain worldwide leadership in advanced materials technology. Attractive Government aid packages to the industries already developed, or in the process of being set up, deserve serious consideration.

5 Recommendations

The following recommendations are made taking into account not only the needs of our country but also the constraints imposed by lack of resources and specialist manpower. Thus, though there is a continuous materials development activity the world over in almost all fields of endeavour, only a few of them can be selected for concentrated research and development. It is almost clear that in the case of most of the advanced materials, the R&D status in India does not compare well with that of the developed nations. Therefore, programmes have to be formulated and progressed rapidly in selected areas if we wish to keep up with the developed nations. Finally, as emphasised earlier in this report, the development of advanced materials invariably requires sophisticated processing technologies and manufacturing engineering. The material development programme should therefore not only include the development of the basic materials but also the associated processing and manufacturing aspects.

Separate recommendations on research areas appear in section 5.1, on integrated development in sections 5.2a, 5.2b, 5.2c and on implementation in section 5.3.

5.1 Research Areas Recommended for Intensified Effort

Advanced materials present a fertile field for new research contributions. Given adequate support, creative effort of Indian research groups has every chance, at the present juncture, of making an impact upon the international scene. Some of the advanced materials, and the promising areas of research with respect to these materials, for intensified indigenous effort, are given below.

Ceramics

In the area of high temperature mixed oxide superconductors (T_c now commonly as high as - 180°C), which are engaging worldwide attention, research needs to be directed to overcome (a) problems associated with fabricating useful shapes such as wires and tapes and (b) problems related to achieving a critical current density of about 10^6 Amps/cm^2. The present drive towards discovering new materials with still higher transition temperatures is proving to be profitable as well and offers a major area of fruitful research along with theoretical and structural aspects related to the understanding of the phenomenon of superconductivity.

While the development of zirconica ceramics is being recommended for an integrated development effort in section 5.2c, another class of structural ceramics requiring intensified research is nitrogen ceramics: silicon nitride and sialons are promising systems for high temperature applications, including the most challenging one of the aircraft gas turbine engine. Although these materials have been known for some time now, a greater research effort, in terms of processing - structure - properties, is called for to ensure the best possible performance in actual application. Synthesising sialons from cheaper raw materials also deserves to be investigated.

One universal drawback with ceramics is their low fracture toughness and probabilistic fracture strength. An attractive way to improve the above property is through the use of Ceramic - Matrix Composites (CMC) like SiC/Al_2O_3, SiC/Si_3N_4, SiC/glass and SiC/SiC etc. The critical issues requiring immediate attention in the development of CMSc are: (a) development of thermally stable SiC fibres and whiskers; (b) improving our understanding of the oxidation behaviour; and (c) understanding of the interfacial phenomena and development of fibre coating technology.

Polymers

Fundamental investigations on new generation Ziegler-Natta catalysts which enable the control of the molecular architecture of the polymer in modern gas phase polymerisations are critical. Better understanding of initiator systems, including bifunctional initiators undergoing decomposition in two stages, will be particularly important in the preparation of novel block copolymers. Understanding of polymer surfaces and interfaces through systematically acquired scientific knowledge will lead to major breakthroughs. The role of coupling agents, analysis of thermodynamics, composition and organisation of interface regions of polymers are important in this context.

Polymer blends are assuming great importance. Thermodynamic theories for block copolymers and blends, investigation of morphology and theological properties of microphase separated systems, kinetics of phase separation in blends are challenging areas of research.

Investigation of molecular composites, especially involving an innovative concept of mixing rigid rod polymer molecules with a chemically similar matrix of flexible molecules is an exciting idea that needs to be pursued. The main challenges are to achieve higher molecular weights of rod-like molecules and also uniform dispersion in the flexible matrix.

The solution of boundary and initial value problems, relevant to polymer processing, requires modern tools of analysis involving difficult computational techniques. The description of the state of stress in a polymer fluid, as the polymer undergoes solidification in a processing operation, is of key importance in determining the properties; but it is ill-understood today. Complexities of nonlinear rheological behaviour, prediction of orientation in flow, and thermodegradation chemistry make the task a challenging one.

A fundamental understanding of polymer degradation and stabilisation is crucial, since in this way polymer science can contribute to the nation's need for conservation of natural resources. A better understanding of the pathway by which polymers are degraded can be obtained now with the improved sensitivity of modern analytical techniques. Polymers are known to degrade faster under mechanical stress but the chemical reasons for this are not yet clear. Prediction of long term stability is an art rather than a science and breakthroughs in this area are badly needed.

Metallic Materials

The requirement for ever increasing density-normalized properties (specific modulus, specific strength) by the aerospace industry has led currently to the development of Al-Li alloys for airframe structural use and intermetallic alloys for aeroengine components. In the case of Al-Li alloys, the dominant research problems yet to be tackled are: (a) study of the influence of microstructural features like the grain boundary precipitate structure, size and shape, precipitate free zone with slip planarity and grain size/subgrain size on the tensile behaviour, fracture toughness and fatigue properties; and (b) use of novel alloying additions which mitigates slip planarity without the disadvantages of Cu and Mg - which adversely affect density, modules and segregation characteristics. Among a variety of intermetallics based on Ni, Fe, Ti and Al, titanium aluminides have shown the greatest promise for aircraft engine applications with a high temperature capability matching that of commercial nickel alloys such as Inconel 718 at half their density. The research areas requiring intensified efforts can be listed as follows: (a) understanding of creep and fatigue mechanisms; (b) study of phase equilibria; and (c) optimisation of processing route (casting/powder metallurgy/isothermal forging) to obtain the required ductility.

Rare earth (RE) metals and alloys are used extensively in catalysts and chemicals, in emerging superconductors and magnetic materials, for shape control of inclusions in steel, in glass/ceramics and as ferro-electrics and optoelectric materials. The areas requiring extensive R&D effort are: (a) development of RE based or RE doped advanced catalysts for widespread use in applications such as petroleum refining and synthesis of organics; (b) fundamental work in developing new techniques for the separation and production of pure as well as mixed rare earths, (c) R&D for ultrapurification of RE and (d) development of Ti-, Mg- and Al-based alloys with substantial RE metal additions for aerospace applications.

The use of ceramic fibres like SiC in a metallic matrix (metal matrix composites) can result in significantly higher specific strength and stiffness when compared to the base metallic alloy. The thrust areas for R&D in MMC can be listed as: (a) manufacture of high quality SiC fibres and whiskers; (b) development of processing techniques specific to MMC based on casting and powder metallurgy routes and (c) understanding of the mechanical behaviour of MMC.

Steels have been the dominant metallic material for structural applications and promise to continue to be so for quite some time. The development of steels and their use has been driven by the principle of higher strength with adequate formability and ductility. Modern structural applications such as aerospace, surface transportation, ocean going vessels, oil pipelines have highlighted the requirement of fracture toughness. As a result, a revival of basic research in terms of cleaner steels (e.g removal of phosphorus, novel heat-treatments (e.g. bainitic treatments) and alloying (e.g. nitrogen steels) in the area of steels has just begun and offers new opportunities.

5.2 Materials Recommended for Concentrated Development

While selecting advanced materials for concentrated development, it has been noted that separate programmes already exist for crystalline silicon (Department of Electronics) and amorphous silicon (Department of Nonconventional Energy Sources). In regard to high temperature superconductors, a National Programme Management Board has been constituted with Prof C N R Rao as the Chairman, and with its Secretariat in DST; the apex body for this programme is chaired by the Prime Minister and an allocation of Rs. 18.4 crores has been made. For the development of optical fibres technology, collaboration for production within the country has recently been finalised. Similarly, development of Al-Li alloys and gas turbine materials, mainly for defence applications, is being pursued within DRDO. Development of phosphor materials and high volume low value commodity plastics may be left to the industry. IPCL has taken the initiative to establish an application engineering centre, with overseas collaboration, for the indigenous development of engineering plastics. Taking all this into account, and the constraints stated above, it is recommended that a concentrated and comprehensive effort should be made with regard to the following advanced materials:

- Metals and Alloys : Titanium
- Electronic Materials : Silicon-based microelectronics and III-V Semiconductor compounds
- Magnetic Materials : Nd-Fe-B
- Ceramics : Zirconia
- Composites : a) Carbon, SiC, Kevlar fibres
  b) Carbon composites.

5.2a Metals and Alloys: Titanium

We shall take up the case of titanium in some detail for a comprehensive illustration of the suggested approach to ensure a major development.

India is richly endowed in terms of titanium minerals (more than 20%

of world resources) and, in this context, titanium acquires a special significance. At present the extent to which titanium is used in our country is insignificant when compared to the levels of consumption reported by the developed countries. It is therefore necessary to adopt a deliberate policy of nurturing its growth and promoting its widespread use, for example, by using titanium tubing for all powder plant condensers.

The salient features of the Indian titanium scene depicted in *Fig. 8* are:

- A well-established beach sand industry for mineral separation exists in the country at Dhranghadara Kerala Minerals and Metals Limited (KMML) and Indian Rare Earths (IRE).

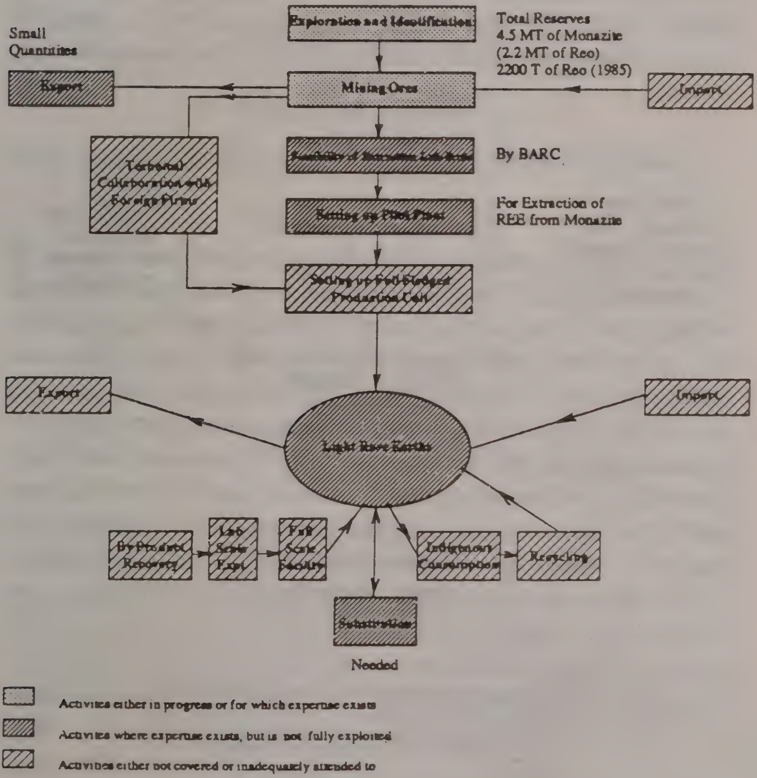
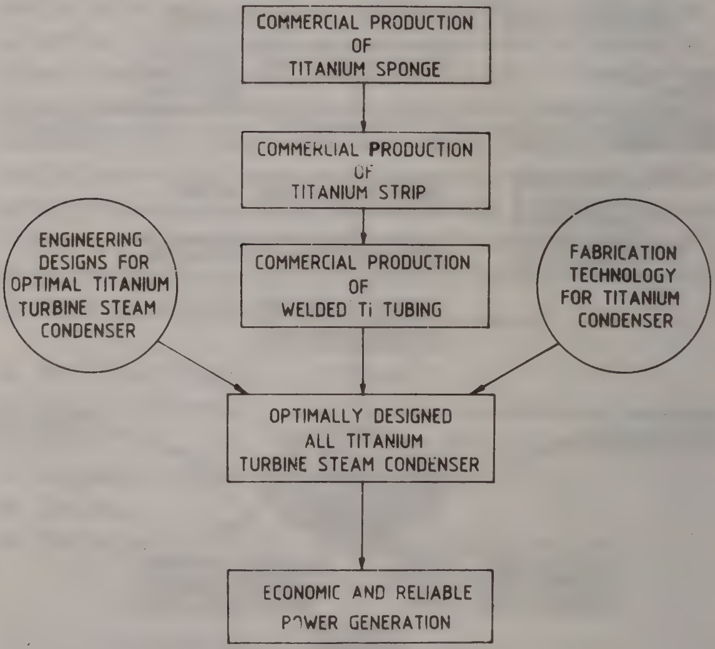


Fig. 8 The Indian titanium scene.

- Large scale production facilities for synthetic rutile (IRE, KMML), titanium tetrachloride (KMML) and pigment grade titanium dioxide (KMML, Travancore Titanium Products) are in operation.
- No commercial plant exists for the production of titanium sponge metal and the country's requirement is met entirely by imports.
- Capacity for mill products production exists at Midhani.
- Capability to design a steam condenser exists at BHEL, and this needs to be harnessed.


COMMERCIAL PRODUCTION OF TITANIUM SPONGE
COMMERCIAL PRODUCTION OF TITANIUM STRIP
ENGINEERING DESIGNS FOR OPTIMAL TITANIUM TURBINE STEAM CONDENSER
COMMERCIAL PRODUCTION OF WELDED Ti TUBING
FABRICATION TECHNOLOGY FOR TITANIUM CONDENSER
OPTIMALLY DESIGNED ALL TITANIUM TURBINE STEAM CONDENSER
ECONOMIC AND RELIABLE POWER GENERATION

NOTE:

1. FOR STEPS INDICATED WITHIN ○ DEVELOPMENT OF TECHNOLOGY IS ESSENTIAL
2. FOR ALL OTHER STEPS INDIGENOUS TECHNOLOGY IS AVAILABLE

Fig. 9 Titanium condensers for economic power generation.

- Technology for equipment fabrication is available at BHPV and BHEL but needs augmentation in respect of application such as power plant condensers.

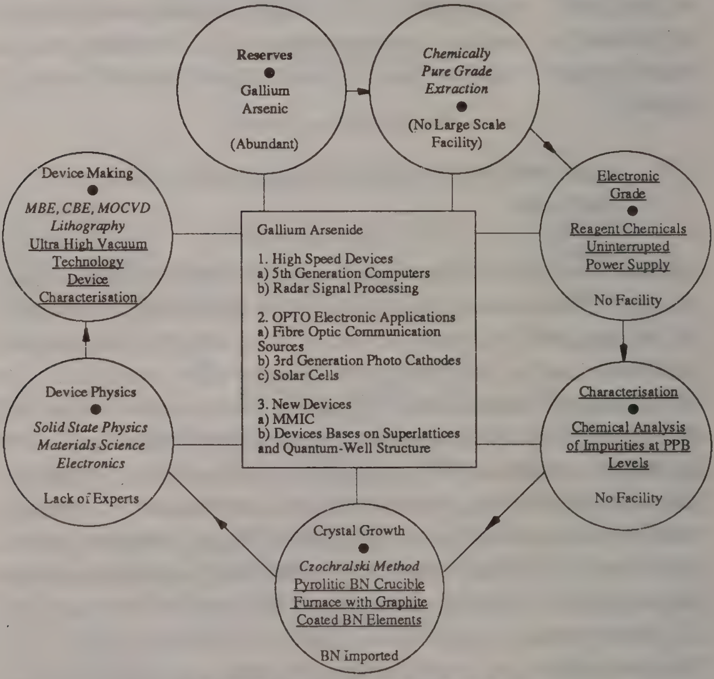
Till now, technology for metal production on an appropriate scale was not available for ready exploitation. This gap has been bridged with the establishment of the Development Technology Centre at DMRL. However a full-scale commercial plant is yet to be set up. Large scale manufacture of titanium tubed steam condensers, requiring further inputs as shown in *Fig. 9*, is needed before the country can be said to be in a position to make such a titanium based industrial system. Efforts are now underway to establish a titanium welding facility at Midhani, with a view to move a step closer towards ensuring the use of titanium in power plant condensers in India. The other steps in regard to steam condenser design, fabrication and use will hopefully follow.

5.2b Electronic Materials: Silicon-based Microelectronics and GaAs

Silicon-based microelectronics is the predominant component of the present-day electronics industry worldwide and is likely to remain so far at least another decade. If India has to achieve technological excellence, and at the same time become cost competitive, the development of silicon-based microelectronics on a much large scale than at present is essential. In this context a recent report by the Joint Scientific Committee (JSC) to the DoE is relevant. Its suggestions in respect of the following deserve serious consideration: (a) development of process techniques to fabricate multilayer, advanced printed circuit boards; (b) establishment of remote design centres to increase the availability of design software and hardware for design of ICs; (c) development of application specific integrated chips (ASIC) for mass market line of a PC costing Rs.3000, consumer electronic goods and telecommunications; (d) development and demonstration of a mature VLSI design competence by designing a 16-bit microprocessor.

Figure 10 illustrates the total picture from raw material to component/device development in the case of GaAs. In this figure, the activities/processes available to an adequate degree are shown in bold print; elements underlined are totally absent in the country, and hence require immediate attention. Elements shown in italics represents an intermediate situation. From Fig. 10 it is clear that in the case of large-scale production of GaAs based devices, the major inadequacies relate to ultra high vacuum technology, and the indigenous non-availability of reagent chemicals and boron nitride crucibles.

The application areas for GaAs based devices are listed in the central square box. Again it is relevant to point out that the Joint Scientific



- ● Activites/processes available to an adequate degree are shown in **bold print**
- ● Activities/processes inadequately attended are *italicised*
- ● Activities/processes not available are underlined

Fig. 10 Current status and gaps in the chain of activities with respect to GaAs.

Committee to DoE has advocated that the development of indigenous designs for GaAs MMIC, for use in microwave and satellite communications, is to be an immediate and tangible goal. The case is very strong for such a programme since it is anticipated that 10,000 systems (having GaAs MMIC) will be required over the next year.

5.2c Other Selected Materials

The current status and gaps in the chain of activities with respect to the other selected advanced materials, i.e. Nd-Fe-B, zirconia, SiC

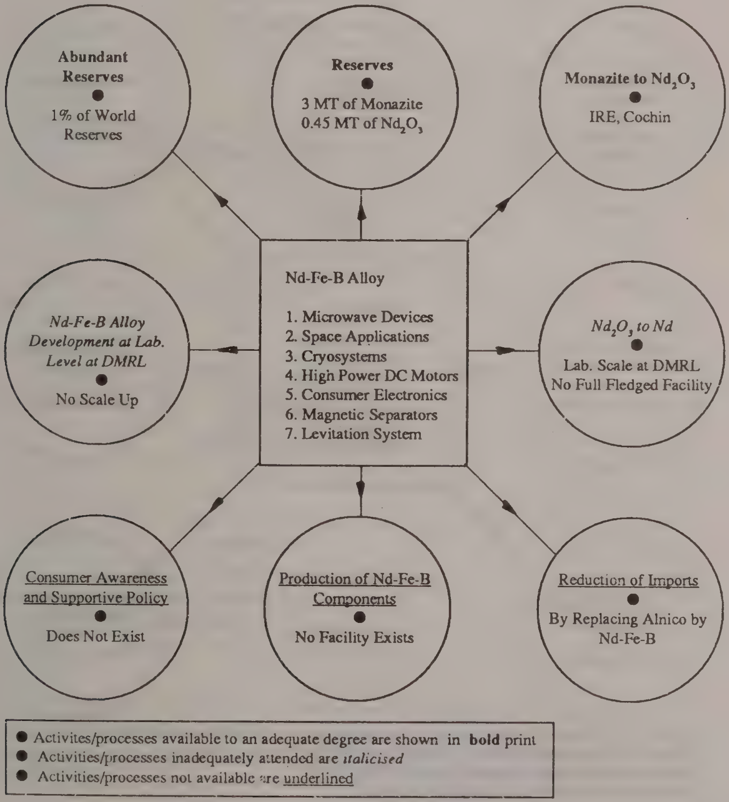


Fig. 11 Current status and gaps in the chain of activities with respect to Nd-Fe-B alloys.

fibre, carbon-polymer composites and carbon-carbon composites are illustrated in *Figs. 11-15* respectively. If we can succeed in developing the entire chain of activities, for each of the chosen examples of advanced materials, we would have succeeded in generating the needed culture that can provide the ambience for undertaking innovative development and production of advanced materials.

The *Figs. 11-15* are self-explanatory and indicate the approach that one should adopt in analysing the existing gaps with reference to the

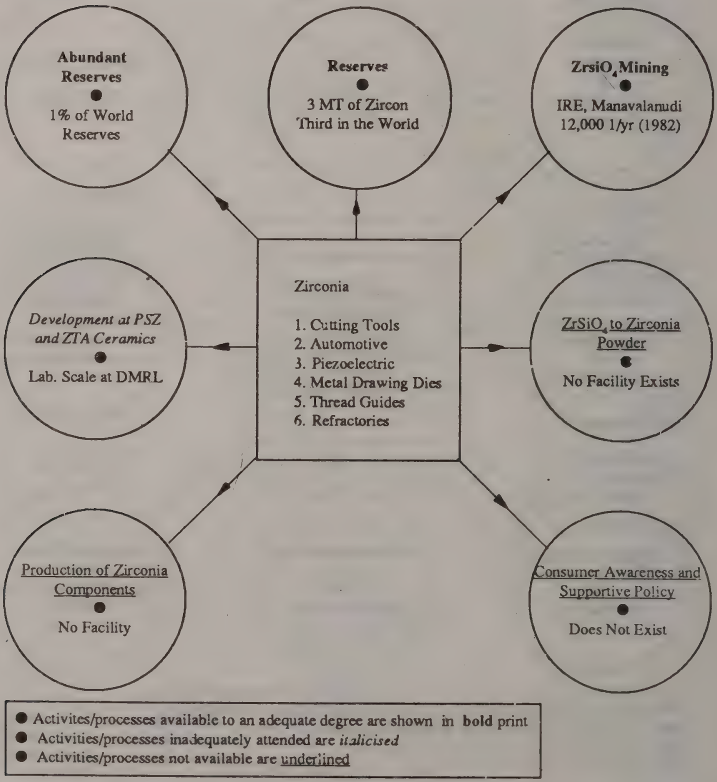
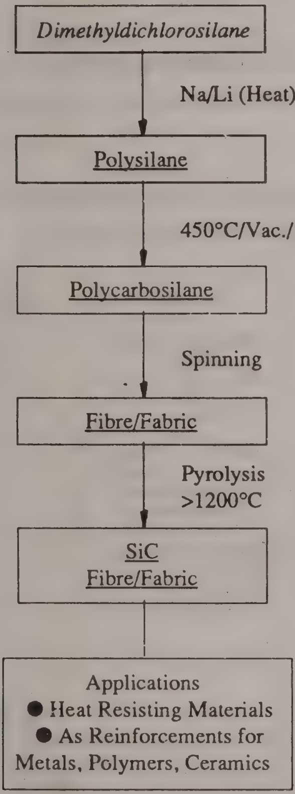

Abundant Reserves
●
1% of World Reserves
Reserves
●
3 MT of Zircon
Third in the World
ZrsiO4 Mining
●
IRE, Manavalanudi
12,000 1/yr (1982)
Development at PSZ and ZTA Ceramics
●
Lab. Scale at DMRL
Zirconia
1. Cutting Tools
2. Automotive
3. Piezoelectric
4. Metal Drawing Dies
5. Thread Guides
6. Refractories
ZrSiO4 to Zirconia Powder
●
No Facility Exists
Production of Zirconia Components
●
No Facility
Consumer Awareness and Supportive Policy
●
Does Not Exist
● Activites/processes available to an adequate degree are shown in bold print
● Activities/processes inadequately attended are italicised
● Activities/processes not available are underlined

Fig. 12 Current status and gaps in the chain of activities with respect to zirconia.

total picture from raw materials to component/device development. It is therefore not necessary to discuss each of these figures in detail. However, it is nevertheless instructive to point out the major inadequacies pertinent to each of the chosen advanced materials.



- Activities/processes inadequately attended are *italicised*
- Activities/processes not available are underlined

Fig. 13 Current status and gaps in the chain of activities with respect to silicon carbide fibre.

Nd-Fe-B alloy

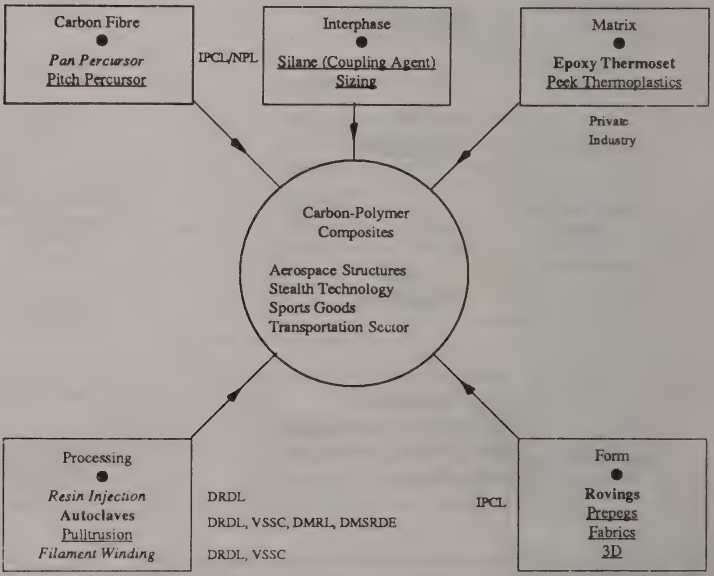
- Large scale ion exchange solvent extraction facility for separation of individual rare earths.
- Large scale production of Nd

Zirconia

- Large scale production of zirconia powder

Silicon carbide fibre

- The complete process know-how to be established applies equally well to other fibres like Kevlar and carbon



- Activites/processes available to an adequate degree are shown in **bold print**
- Activities/processes inadequately attended are *italicised*
- Activities/processes not available are underlined

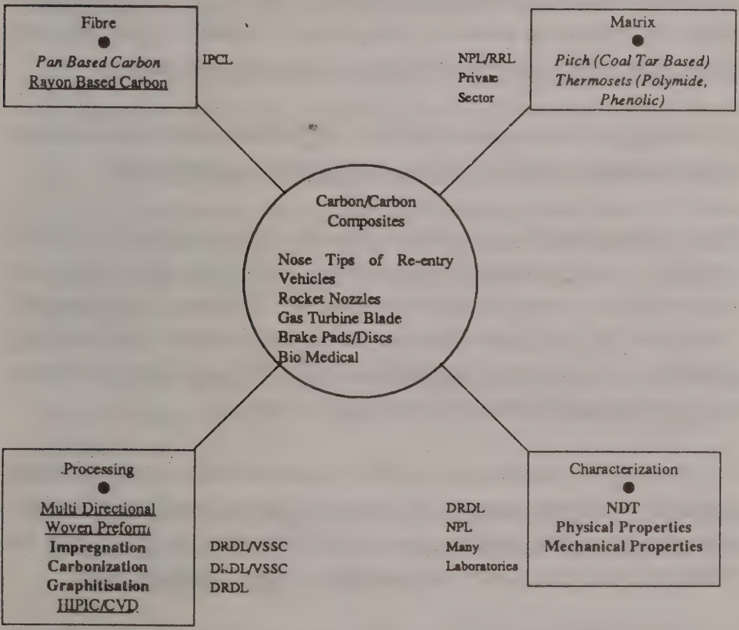
Fig. 14 Current status and gaps in the chain of activities with respect to carbon polymer composites.

Carbon/Polymer composites

- Precursor and resin development
- pulltrusion facility
- weaving into various forms

Carbon/carbon composites

- Precursor development
- Multi-directional woven preforms
- Fabrication of hot isostatic pressing (HIPIC) and CVD units (both banned items).



- Activites/processes available to an adequate degree are shown in **bold print**
- Activities/processes inadequately attended are *italicised*
- Activities/processes not available are underlined

Fig. 15 Current status and gaps in the chain of activities with respect to carbon-composites.

5.3 Recommendations Regarding Implementation

There is a clear need to have a body at the national level to launch, coordinate, review and monitor programmes in the area of advanced materials. Such a body can be called the National Advanced Materials Research and Development Board. Only such a body can have the necessary knowledge of, and the authority to mobilise, the existing capabilities, and recommend installation of additional facilities. The research areas and the list of materials for integrated development suggested above can be reviewed by such a national board which may then constitute separate task forces consisting of chosen expert scientists and technologists in each case. This arrangement offers the best hope of a complete understanding of the scientific, processing and manufacturing challenges involved. If we can make this arrangement work then the dream of indigenously developing newer, and more innovative, materials in India is certainly realisable.

A few suggestions are made below in regard to the task forces needed to assist the National Board, as and when it is constituted.

Task forces should be constituted for each of the advanced materials. Initially, one or two leading personalities in the concerned field may be identified to assemble a group of experts. This task force then will formulate the R&D programme taking into account the existing facilities in the country, and the constraints of funds. The task forces may be charged with the following functions:

- Review the current status with respect of R&D of the relevant material within the country. In particular, the universities, laboratories and industries, wherein such an activity is in progress, may be identified and the quality and quantum of their work assessed.

- Consider the future demand for the material within the country and draw up a list of specific products to be developed and produced in quantities required.

- Decide on the most appropriate technology/process for each of these materials, taking into consideration the economy of the process as well the Indian resources position. It is important that the most appropriate process/technology is chosen for all elements of the flow sheet, right from the extraction of the ore to the manufacture of the device/component using the material.

- Using the flow sheet, make a detailed list of equipment, trained personnel and infrastructure required for the successful completion of the programme. Estimate the total cost of the programme.

- Keeping in view the facilities and expertise available in the country, decide whether a separate laboratory/technology centre should be set up or whether existing laboratories/industries can carry out the programme successfully if suitable linkages are established, and a programme of coordination is drawn up.

- Arrange a detailed project proposal to be prepared, if necessary through the involvement of an engineering consultancy organisation.

- After the approval of such a project, organise further steps for the allocation of funds to the various laboratories, universities or industry involved in the programme. If a new laboratory has to be set up, decide on a suitable site and a pool of experts who will set up and run the laboratory.

- Once the programme gets started, regularly monitor the progress of the programme and coordinate the activities among the various institutions.

- The task force should also concern itself with the long range plans for the acquisition of a pool of experts who can lead the R&D effort on advanced materials in the future.

In this regard a B.Tech level course on Materials Engineering (including ceramics, polymers, glasses, composites, electronic materials apart from metallic materials) should be formulated and implemented in one or more of the Indian Institutes of Technology. To start with, the number of admissions may be limited to about 15.

Appendix-1

Materials for the year 2000: National Priorities

K J Rao and S Ranganathan

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Materials for the year 2000

Synopsis

A reliable index of the prosperity of a country is the extent of new materials in its use. In the process of harnessing natural resources, new materials are constantly synthesised. Present day civilisation employs a very large number of materials in quantities small and large. The change in the pattern of their usage is also very rapid. Any exercise intended to predict the nature or number of materials in use roughly one and half decades from now is beset with large uncertainties. Materials priorities of a country are determined by its needs and they should get reflected in its materials programmes. However, we should recognise that materials programmes are also influenced by many other factors such as natural resources, ethnic response (to the adoption of new material) socio-economic and even geo-political factors.

As we near the end of this millenium, we are caught in a dilemma with regard to the approach we should make in facing the materials challenges of our country. India is an ancient civilisation with a large rural population. Indians are an extraordinary people whose ethos dictate austerity and renunciation as a means to happiness. Their philosophical tenets require them to achieve harmony with nature and interact with it nondestructively. Significantly, these are just not the beliefs and pursuits of the materially advanced West. Our current models for the materials development in the country are however strongly influenced by the West. The dichotomy of our perceptions is compounded by the rapid changes which have occurred in the materials scene of the world over the past few decades. These changes have always left our so called "developing country" in an ever increasing phase lag with respect to, and a constant and continued dependence on, the highly industrialised countries.

We should admit that the gigantic materials problems of a country like ours cannot be solved by simplistic approaches. Hence our materials programmes should be in response to the pressing needs of a materials-hungry society and not be perambulations into the esoteric. Therefore this report sets out to seek and sort out select materials of importance where thrust is essential to make our country provide itself against impending ravages of poverty and over population. An essay on important materials is presented in sections 1 and 2. Section 1 includes electronic, magnetic and such non-structural materials whose requirements in terms of tonnage may not be high but the materials are often strategic. Section 2 is an overview of structural materials which are vital for development and voluminous in their requirement. Any advancement in materials is not feasible without associated advancement in material technology. It is common knowledge now that the real bottleneck in materials programmes is the lack of preparative and processing technologies and less frequently the nonavailability of resources. Processing technologies are developed at great cost in advanced countries and the knowhow is guarded through patents, shrouded in secrecy and shared with developing countries only at exorbitant prices charged to the latter. Methods of characterisation and quality control are also inseparable aspects of advanced materials technology. So much is happening in the advanced countries with regard to new technologies and non-destructive methods of material characterisation that, unless they become an integral part of our materials culture, all efforts or investments in materials programmes could easily get thwarted. Section 3 refers to some relevant materials processing technologies in this context.

This is followed by a recommendatory section 4 in which only important materials are highlighted sectorwise such as in transportation, communication, energy and so on. A summary form of these materials is contained in section 5.

It is important to note that reliable estimates of the materials needs of the country in various sectors are simply not available. Wherever such data are available, they are included in this report. In certain vital sectors, where new materials are likely to make a significant impact, guess estimates of the needs are also provided. The current level of funding and activities in some of the Western countries is also included in section 5 for thoughtful comparison wherever such data are available. ■

1 Non Structural Materials - An Overview

1.1 Electronic Materials

1.1a Semiconductors

Crystalline silicon forms the rockbed of semiconductor electronics today. Both computer industry and other conventional applications are based on devices made from crystalline silicon. Silicon also forms the large base in photovoltaic energy conversion. At present, the scenario is gradually changing. Crystalline silicon is being replaced by amorphous silicon on the one hand and by gallium arsenide on the other. The discovery that amorphous silicon could be doped with elements of III and V group, and hence n-p junction could be realised with amorphous silicon, has opened up tremendous possibilities. Under their ''Operation Sunshine'' programme, the Japanese have demonstrated that the entire range of sophisticated devices including MOSFETs' CCDs etc. can all be fabricated with amorphous silicon. Using heterojunction structures with layers of amorphous silicon carbide, photovoltaic conversion efficiencies of well over 10% have been achieved in large area structures.

The choice of semiconductor material for the future generations of computers is shifting to gallium arsenide. This ensues very simply from the fact that the electron mobilities in gallium arsenide is of the order of 9000 $cm^2V^{-1}s^{-1}$, which is six times higher than in silicon. Unlike silicon, GaAs is a direct band gap material. The energy gap in gallium arsenide is quite manipulatable by doping with aluminium or indium. In fact, with aluminium doping, gallium arsenide wafers of 1 μm thickness can be prepared with about 0.2 electron volts decrease in the gap end to end. This is important in the fabrication of many devices such as High Electron Mobility Transistors (HEMT). The switching time in GaAs devices is of the order of 10 ps., making them superior to silicon for computer applications. At present it is uncertain if the development of computers based on Josephson junctions (SQUIDS, Super Conducting Quantum Interference Devices) would get revived because of the discovery of new superconductors.

However, gallium arsenide appears to be the best semiconductor for the computer industry. Perhaps, gallium arsenide based computers may incorporate interconnections of superconductor strips. It should be noted in this context that evolution of advanced super computers with mind-boggling capabilities are based on revolutionary changes in computer architecture such as 'piping' and 'parallel computing', and not simply on the use of new materials.

A variety of III-V and II-VI semiconductors are used by the electronic industry. The applications of III-V semiconductors range from light emitting diodes to magneto resistive elements in integrated circuits. A few III-V semiconductors are also the best photovoltaic materials. Perhaps, they are best reserved for highly specialised applications (gallium arsenide and aluminium doped gallium arsenide have been found to give rise to photo-voltaic efficiencies of the order of 23.8% at air mass of 2 and 1000 suns). Some of the important current applications of III-V semiconductors are shown in Table 1. III-V semiconductors based on gallium arsenide doped with other 3rd and 5th group elements constitute the base of light emitting diodes vital for optical communication. $GaAs_{1-x}P_x$ and $GaIn_{1-x}P_x$ are of vital importance in this respect.

Table 1

Typical Applications of III-V Semiconductors

Application	Preferred compound or alloy system
Optoelectronic infrared-emitting diodes	GaAs, $Ga_xIn_{1-x}As$, $Ga_xIn_{1-x}As_yP_{1-y}$
Light-emitting diodes	$GaAs_{1-x}P_x$, GaP, $Al_xGa_{1-x}As$
Fibre-optic sources	$Al_xGa_{1-x}As$, $Ga_xIn_{1-x}As_yP_{1-y}$
Optical detectors	InSb, InAs, GaAs, $Ga_xIn_{1-x}As$
Optoisolators	GaAs, $GaAs_{1-x}P_x$
Injection lasers	GaAs. $Al_xGa_{1-x}As$, $Ga_xIn_{1-x}As_yP_{1-y}$
Integrated-optic structures	GaAs, $Al_xGa_{1-x}As$
Negative-electron-affinity devices	GsAs, GaP, $Ga_xIn_{1-x}As_yP_{1-y}$, $Ga_xIn_{1-x}As$
Photovoltaic cells	GaAs, $Al_xGa_{1-x}As$
Electrooptic modulators	GaAs
Microwave Transferred-electron (Gunn)devices	GaAs, $Ga_xIn_{1-x}As$, InP
Field-effect transistors	GaAs. GaAs. $Ga_xIn_{1-x}As$, InP
IMPATT diode	GaAs
Integrated circuits	GaAs

The large number of phosphor materials needed for television and video display terminals continue to be provided by II -VI semiconductors based on ZnS and (Zn, Cd)S. Cadmium telluride is used in electrooptic modulators required in CO_2 lasers and in other infrared transmission applications. Infrared detection systems are based on the use of HgCdTe. Coherent infrared source in 4-20 µm region is made of Pb(S,Se)and (Pb,Zn) Te based diodes. These semiconductors will continue to be in significant demand at the turn of the country. Chalcogenides such as amorphous tellurides and amorphous selenides are at present used extensively in reprography and mass memory modules. Reprography is however shifting to the use of amorphous silicon. Photo structural effects, observed in amorphous chalcogenides, have again opened new possibilities of mass information storage and retrieval through the use of lasers, and are likely to dominate the scene shortly.

1.1b Superconductors

An area of materials most intensely investigated during the past two decades in the face of much frustrations has been superconductors. Indeed, most summaries on the subject till recently have been quite sceptical about the possibility of any major breakthrough in this area. During the last three months hopes have risen sharply through the discovery of superconductivity in mixed valence oxides containing lanthanum, yttrium, copper, barium and strontium. The limit of 23K recorded by Nb_3Ge in the early seventies has soared upto 160 K in 1987. It is rumoured that the highest has already hit the 273K mark. Some of these discoveries may be serendipitous. Hopes are therefore now raised that these discoveies may result in gainful technologies related to levitation transportation, power transmission and development of powerful magnets (needed for use in medical electronics such as in whole body scanners and in magneto hydrodynamic power generators). It definitely unleashes new energy into the research in high energy physics.

1.1c Ferroic Materials

The electronic industry employs a variety of ferroelectric and ferroelastic materials. In Tables 2 and 3 a number of important ferroelectric and ferroelastic materials currently in use are tabulated along with the magnitudes of their characteristic properties. With the increasing miniaturisation of electrical circuits using VLSI (very large scale integration) and multilayer technology, continuous demands are made for better materials with tailored properties. Several of the materials listed in tables 2 and 3 are often needed in relatively small quantities but they are of strategic importance. Single crystalline $LiNbO_3$, YAG, YIG etc. are used as optoelectronic materials and are needed in significant quantities. Ferroelastic materials such as GMO and TMO find applications in colour modulation and ferroelastic optical switching (to provide saturated interference colours, green to blue to red). These are relatively recent developments not yet in common use in domestic industry. These materials are likely to become quite widely used by the end of the century alongside ADP, KDP, KTN, $Ba_2NaNb_5O_{15}$ (BANANA), PLZT and PZT.

Table 2

Some important ferroelectric materials[+]

Materials	T_c(K)	P_s($10^{-2}Cm^{-2}$)
Ammonium dihydrogen phosphate (ADP) ($NH_4H_2PO_4$)	148	*
Barium Cobalt fluoride ($BaCoF_4$)	melt below Tc	8
Barium titanate ($BaTiO_3$)	183,278,393	20
Borocite ($Mg_3B_7O_{13}Cl$)	538	0.05
Guanidinium aluminium sulfate hexahydrate (GASH)[$C(NH_2)_3Al(SO_4)_2.6H_2O$]	decomp	0.05
Lead titanate ($PbTiO_3$)	63	75
Lead zirconate ($PbZrO_3$)	503	*
Lithium niobate ($LiNbO_3$)	1473	71
Lithium tantalate ($LiTaO_3$)	938	50
Potassium dihydrogen phosphate (KDP) (KH_2PO_4)	123	5
Rochelle salt ($NaKC_4H_4O_6.4H_2O$)	255,297	0.25
Sodium niobate ($NaNbO_3$)	73,627	*
Terbium molybdate (TMO)[$Tb_2(MoO_4)_3$]	436	0.2
Triglycine sulfate [$NH_2CH_2COOH)_3.H_2SO_4$	322	2.8

[+] based on a recent authoritative compilation in Encyclopedia of Materials Science and Engineering, Editor-in-chief, M B Bever, Pergamon Press, 1986.

[*] antiferroelectric at room temperature

1.1d Optical Fibres

Another vital material related to electronic communication industry is the optical fibre, the wave guide for optical communication. The novelty and splendour of new materials is brought to sharp focus in optical communication. It is now good bye to metal wires (of copper and aluminium) in communication industry after the finding that light waves can carry signals at far greater densities when piped through extremely transparent glass fibres. Loss of light intensity is further remedied by cladding the fibre with another

Table 3
Some important ferroelastic materials⁺

Formula	$10^6 e_s$	$E_{ij}(ij)$ (MNM^{-2})
$CsFeF_4$	320	22(13)
$K_2Cd_2(SO_4)_3$	58	*
KIO_2F_2	3100	2(13)
$LaFeO_3$	240	300(12)
$MgB_7O_{13}C$!(borocite)	550	120(12)
PtGeSe	4300	16(12)
$SmAlO_3$	56	50(12)
$Tb_2(MoO4)_3$	2000	1.5(12)
$Gd_2(MoO_4)_3$ (GMO)	1600	1.0(12)

⁺ based on a recent authoritative compilation in Encyclopedia of Materials Science and Technology Engineering. Editor-in-chief, M B Bever. Pergamon Press, 1986.

* Frozen ferroelectric (23)

layer of glass of lower index. At present, transmission of information in silica fibres is possible at the rate of 140 megabits/sec over 30 kms distance without the use of repeaters. Optical loss has been brought down to an incredible minimum of 0.2 dB/Km at wavelengths of 1.3 and 1.55 µm. These are the frequencies generated using LEDs based on some of the III - V semiconductors of Table 1. Oxide free glass fibres based on heavy metal fluorides have recently proven to be even more suitable for optical fibre communication.

1.2 Industrial Sensor Materials

A class of largely ceramic materials whose applications are due to their electronic properties are the sensors employed in various industries. These sensors include piezo electric devices, negative temperature coefficient thermistors, PTC resistors, varistors etc., The materials in use are PZT (lead zirconate titanate) $BaTiO_3$, ZnO and a few other mixed transition metal oxides. The response of some of the sensors also originates from the ionic nature of the system like in stabilized zirconia whose conductivity is sensitive to oxygen partial pressure and hence is used as an oxygen sensor.

There are similarly humidity sensors and sensors for toxic and combustible gases. These are again based on a variety of mixed oxides made from magnesia, chromia, titania, alumina and semiconducting oxides of tin, zinc and iron. There have been many advances in the area of sensor chemistry and technology. A large volume of sensor materials needed particularly in the control of combustion and exhaust emissions in automobiles and in steel industries are based on zirconia and titania. Sensors are also used in biomedical devices and in a variety of consumer electronic items such as microwave ovens, TV sets etc. In Table 4, a summary of the currently important sensor materials are listed.

1.3 Laser Materials

Lasers have been with us for quite a long time. The application of lasers has been growing exponentially. Lasers constitute a controllable source of intense energy which can be delivered accurately on to selected objects. This has made them pervade diverse areas like biomedics to range finder to resistor trimming to star wars. The potential for its use in India is very large; for example, carbon dioxide lasers at 10.6 μm wavelength are today extensively employed in laser machining and so are the Nd-YAG lasers. It is disheartening, however, that our lasers are almost entirely imported.

1.4 Magnetic Materials

A variety of magnetic materials are in use today. In large scale applications such as magneto hydrodynamic (MHD) power generation, or in levitation transportation, better superconducting materials than Nb_3Ge or Nb_3Si are needed. Presently Nb_3Ge and Nb_3Si are used in the cladded wire form (cladded in copper). Permanent magnets based on Ni and Co based alloys are used in many applications. The new magnetic materials of prominence are amorphous alloys based on Fe-Ni-P and Fe-Ni-B systems. These are products of the new rapid quenching technology. They possess excellent permeability, extremely low magneto-striction and very high mechanical hardness - all of which are most desirable properties in magnetic recording heads and in high power transformers. The possible applications of the new generation of superconductors based on oxides already referred to are capable of answering the needs of MHD and other high magnetic field applications.

Table 4

Important industrial sensor materials⁺

Sensor category	Sensing mechanism	Typical ceramic material	Applications
Piezoelectric devices	Converts mechanical energy to electrical energy	Lead-zirconate-titanate	Ignitors, photoflash actuators, resonators, beepers in paging devices, ultrasonic devices
Negative temperature coefficient thermistors	Coefficient of resistivity varies inversely with temperature	Complex systems of nickel, manganese, cobalt and copper oxides	Control of nonlinear circuits, temperature measurement, automobile sensors, medical thermometry
Positive temperature coefficient resistors	Electrical resistivity varies positively with temperature	Combinations of barium titanate with either strontium or lead titanate	Self-regulating heating devices, current limiters, sensors for temperature, airflow and liquid level
Varistors	Voltage-dependent resistors with nonlinear electrical junctions at grain boundaries. Electrical properties are essentially temperature-independent	Zinc oxide	Protect electronic equipment from voltage images: TV receivers, microwave ovens automotive electronics

Table 4 *(Contd.)*

Sensor category	Sensing mechanism	Typical ceramic material	Applications
Oxygen sensors	*Zirconia:* an electromagnetic field is produced in response to the equilibrium partial pressure of oxygen. *Titania:* n-type semiconductor chemical equilibrium between oxygen related lattice defects, oxygen gas in surrounding area	Zirconia stabilised with yttria or magnesia, titania	Controlling exhaust emissions in automobiles, process control for steelmaking, combustion control, gas manufacture. Mainly automotive controlling exhaust in 3-way catalytic converter
Humidity sensors	Resistance is a formation of relative humidity of the environment through chemical adsorption, dissociation of water	Magnesia-chrome-titanium, or alumina	Microwave ovens, air conditioners, industrial operations
Combustible and toxic gas sensors	Electrical conductivity responds to changes in gas concentration	Various semiconducting oxides including tin, zinc, and iron oxides	Environmental monitoring, gas leak detection, process control, energy management

Table 4 *(Contd.)*

Sensor category	Sensing mechanism	Typical ceramic material	Applications
	(n-type:flow of negatively -charged electrons conducts electricity; p-type: conducts by flow of positively-charged electron holes)		
Chemical sensor (ion sensitive field effect transition (ISFET)	Surface charge chemistry at gate sensing area varies with the solution ionic concentration which changes voltage or current output	Alumina, silica, silicon oxy-nitride, silicon nitride	Biomedical chemical sensor for measuring pH, humidity detectors
Thermal sensor (pyroelectric)	Current output is a function of the change in the total energy in pyroelectric material	$LiTaO_3$, $PbTiO_3$	Optical sensors, thermal bolometers for infrared measurement, gas flow measurement, enthalpimetry, calorimetry

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[†] Based on an authoritative compilation in Encyclopedia on Materials Science and Engineering, Editor-in-chief, M B Bever, Pergamon Press, 1986.

1.5 Energy Materials

The vision of new materials is blurred by the spectre of the energy crunch in our country. The energy thirst of a developing country like ours appear insatiable. Presently, our primary sources of energy are hydroelectric, atomic and fossil. While the exploitation of fossil fuel has been on a happy note of increase in the country, it is widely believed that our fossil resources are quite limited. The merits of deriving energy from the sun, wind and water, and developing an easily transportable form of energy, which is a dire need for a rural society like ours, can therefore be hardly contested. The importance of new materials to obtain power from solar energy is very evident.

Photovoltaic and photoelectrochemical cells provide two attractive routes to harness solar energy where new materials play an important role. As pointed out earlier, amorphous silicon ranks high for photovoltaic application with a record of efficiency already reaching about 11%. Heterojunction configuration solar cells use a-SiC and microcrystalline silicon thin films along with a-Si. GaAs and CdS are also important high efficiency solar cell materials, of particular value to specialised applications.

The photoelectrochemical cell is an equally important route in using solar energy. A variety of oxide and chalcogenide semiconductors have proven to be effective in this area. Hydrogen and oxygen obtained from splitting water in photo electrochemical cells provide two routes to develop portable energy. One is through the recombination of H_2 and O_2 in fuel cells based on oxygen solid electrolytes like stabilized zirconia. The other is simply burning hydrogen in the manner of other combustible gases like LPG. It is now known that when transportation of energy to any distance more than two to three hundred kms is involved, hydrogen transportation is more economical than conventional power transmission on metal wires. Much progress has occurred in the science and technology of H_2 storage. It is learnt that France has developed lanthanum and iron based alloys which can absorb H_2, providing storage at liquid hydrogen densities.

Electrochemical cells or batteries of diverse nature are currently under development or investigation. In principle, a large variety of chemical reactions can be used for the purpose but only few of these have proven feasible for the production of marketable cells. Ni-Cd and lead-acid batteries continue to be improvised. The choice of other fuel cell materials are conditioned by concurrent developments in solid electrolytes. A few currently investigated battery materials of significant promise to electric automobiles are shown in Table 5. Miniaturized low power batteries which are in great demand, particularly in bioelectronic applications such as hearing aids, heart pacers, etc., are based on the use of lithium and silver batteries. It is thoughtful to take note here of the two international programmes which have succeeded in making tiny batteries based on lithium intercalcation in two layered compounds namely V_6O_{13} and TiS_2. The intercalation itself releases chemical energy. The electrolytes are held in a polymer, PEO, and the electrodes are deposited on supporting polymer films. The entire structure is a multi layered coated polymer from which cells can be punched out and connections added on.

2 Structural Materials - An Overview

Structural materials form the backbone of industrial civilization. The evolution in such diverse fields like urban housing, bridge construction, manufacture of automobiles and aircraft and development of nuclear power has been largely determined by our ability to fashion materials which work under increasingly stringent conditions of stress and temperature, and in corrosive and radiative environments. In view of the development in materials science and engineering, structural materials may be classified into two distinct categories - traditional and advanced. The traditional materials are produced in high volume of low value and are marked by mature technologies. Typical examples are steel, aluminium, cement and glass fibre reinforced plastic. The advanced materials are currently produced in low volume but are of high value and are also distinguished by the application of evolving technologies. New families of engineering materials have become available since 1970. An extrapolation into the next century indicates exciting possibilities. They are the result of consistent striving for obtaining lighter, stronger and tougher high temperature materials. They are largely non-strategic. An additional point of comparison arises in the growth patterns of traditional and advanced materials. While the global production and consumption of aluminium and steel is slackening, advanced materials such as aluminium-lithium alloys, metal-matrix composites and intermetallics are expected to register high growth rates respectively of 18%, 18% and 36%.

As a developing nation, India cannot afford to ignore either traditional or advanced materials. The Indian per capita consumption of common structural materials is still way below international levels. It is necessary to stimulate production through industrial policy backed by research and

Table 5

Candidate Batteries for Electric Vehicles

Battery	Voltage	Theoretical Energy density W/kg	Current Performance Energy Density W/kg	Power (Peak) W/kg	Efficiency %	Cycle life (Nos.)
PbO_2/Pb	2.05	171	30	50-100	60-65	500
O_2/Zn	1.65	1084	110	80	40	600
O_2/Fe	1.28	764	81	30-40	40	200
NiOOH/Fe	1.37	267	55	50-100	60	1500
NiOOH/ZN	1.71	321	71	167	60-65	500

development. In the pursuit of advanced materials we should not lose sight of the importance of traditional and time tested materials. A brief description of the various possibilities in this area is given below. It is the advanced structural materials that hold out much promise. If the country's large scientific base in materials research can be brought to focus on a select set of materials, the resulting benefits will be immense. Aluminium-lithium alloys, intermetallics, zirconia, silicon nitride, kevlar and carbon - carbon composites are projected as suitable examples. The possibilities in this field are very wide. By providing thrust to research and development in a few, but generic type of materials, the country is assured of mastery over many other related materials. Such possibilities are discussed in the following sections.

2.1 Metallic Materials

The dawn of the third millenium is expected to witness a spectacular shift in the pattern of production and consumption of primary metals such as aluminium and steel. Thus China is expected to emerge as the world leader in the production of steel, while the USA and Japan are expected to move to lower positions. Indian production of steel is around 10 million tons per annum and has not risen significantly over the past three decades. Indian estimates for the desired product targets are on the lower side. The report on the national mission for iron and steel estimates the demand for finished steel to be around 22.5 million tons by 2000 A.D. A report by the Chase Econometrics, USA, predicts that the Indian production levels will reach 40 million tons by that time. The changes are brought about mainly because of the saturation of the demand for steel in developed countries, as most requirements such as housing and transport are already satisfied. Countries such as India and China, which are committed to improving the quality of life of large populations, have an almost insatiable demand for consumption of steel.

With the commissioning of the National Aluminium Company Ltd., Orissa, the Indian production of aluminium will reach 500,000 tonnes per annum. Further increase in production of aluminium is not foreseen. With the enormous resources of bauxite, India can well afford to produce more aluminium, provided aluminium is put to diverse uses such as housing and transport.

India has abundant resources of titanium ores. Until recently there was no production capacity. Now, a demonstration plant, producing 250 tons of titanium per annum, is in operation at Hyderabad. Titanium has remarkable corrosion resistance and is very useful as a condenser tubing in thermal power plants and in similar other applications.

Aluminium-lithium alloys offer a density (7.12%) higher stiffness (10%), increased fatigue crack growth resistance and broader environmental capability (Table 6). They promise upto 15% reduction in structural weight and are thus poised for a major expansion as airframe materials.

Table 6

Goals for Aluminium-lithium Alloy Development for Aerospace Application

Ultimate tensile strength	586 MPa
Tensile yield strength	517 MPa
Elongation	10%
K_C	64 MPa$\sqrt{}$m
K_{IC}	23 MPa$\sqrt{}$m
Elastic modulus	69 GPa
Density	2.49 g/cm^3
SCC classification (ST)	C

Academic and R&D institutions in India have been seriously involved in the design and development of aluminium alloys for the past three decades. It is heartening to note that this long experience has been brought to bear on the development of aluminium-lithium alloys during the past two years with encouraging results.

Another remarkable family of alloys are the intermetallics. In a conventional nickel based superalloy, the strength is mainly derived from the dispersion of an intermetallic compound such as nickel aluminide. These compounds can be strong at higher temperatures. Earlier efforts to use them in a monolithic fashion ended in failure due to poor ductility. Just recently it has been demonstrated that addition of small quantities of boron dramatically increases the ductility since boron segregates to the grain boundaries and promotes intergranular cohesion.

2.2 Ceramic materials

The efficient production of cement and its widespread use in reinforced concrete structure marks an important development in housing. Indian innovation in this field has been the use of bamboos as reinforcing elements. The load-carrying capacity of beam reinforced with bamboo is increased by the addition of bamboo splints as diagonal tension reinforcement at sections where the vertical shear is high. A safe design stress of 28 MPa has been achieved with concrete members reinforced with bamboo. When new materials are developed considerable investment in quality control becomes essential. India has again pioneered novel and efficient methods of quality control, employing both chemical and instrumental techniques.

Ceramic materials such as silicon carbide, silicon nitride, sialons, alumina and zirconia together form a nucleus for the development of a new class of engineering ceramics. The thrust for the development of these structural ceramics came from the intense effort made in producing more efficient engine systems. The important requirements for such an engine are low thermal conductivity, high strength, high fracture toughness, high thermal shock resistance, good wear resistance, chemical inertness and high resistance to erosion and corrosion; all at high operating temperatures of an engine.

Zirconia toughened ceramics are extremely promising in this regard. Zirconia is usually stabilised in the desired structure by the addition of CaO, MgO or Y_2O_3. The thermal conductivity of zirconia is extremely low and varies little with temperature. This means that the materials can be used as a thermal barrier coating on turbine blades and in adiabatic diesel engines. The thermal expansivity is relatively high. This is an advantage while joining the ceramic to metallic components. Further India has rich resources of zirconia which makes it extremely important to harness this structural material. Engineering applications of zirconia are based on the fact that zirconia can be toughened. In fact, transformation toughening of zirconia is itself a spectacular effect not yet completely understood. It appears that the ZrO_2 particles are retained in the metastable tetragonal form and are induced to transform martensitically under stressed conditions providing the observed toughness.

Silicon nitride has proved to be a material suitable for high temperature applications particularly for jet engine blades which can enable one to increase the turbine entry temperature. It is also most suitable for making integral moving components of ceramic engines. Several synthetic routes are available for making Si_3N_4. They include chemical vapour-deposition, direct combination of silicon and nitrogen etc. Final shapes (consolidation and compaction) are achieved by hot pressing, reaction bonding and sintering with or without additives. In Germany, USA, and Japan, considerable progress has been made in the use of silicon nitride in automobile engines. Table 7 summarises the estimated energy savings by the use of ceramic engines in the place of metal alloy engines of today.

Table 7
Fuel Savings Projected by the Use of Ceramic Engines

Technology	System's Configuration	Fuel saving, %
Gas turbine		
Automotive	150 hp; regenerated single shaft engine; 1370°C	27
Truck	350 hp; regenerated two shaft engine 1240°C turbine inlet temperature	17
Industrial ship	1000 hp; single cycle three stage engine, 1370°C turbine inlet temperature	10
Diesel engines		
Truck	50 hp; adiabatic turbo compound; 1210°C maximum component temperature	22
Passenger car	80 hp; waterless; 800°C maximum component temperature	10-15

2.3 Polymers and Composites

The high volume, low value commodity plastics include low density polyethylene (LDPE), Polyvinyl chloride (PVC) etc. These materials can be used up to a maximum temperature of 100°C. For higher temperature application, medium volume and medium value engineering plastics are available. Representative examples include polyacetals, polycarbonates, nylons and thermoplastic polymers. The traditional plastics have application in diverse fields like agriculture, transport, housing, engineering and electronics. Indian per capita consumption of plastics is around 0.5 kg compared with the world average of 11 kg. Barrier packaging, with multicomponent polymer systems, provides improved mechanical stability, and reduced permeability, and offers enormous advantage due to the possible reduction of layer thickness of the expensive polymers. Packaging large quantities of fertiliser, sugar, salt, vanaspati and petroleum products present unique opportunities for large scale use of commodity polymers in India.

Polymers such as polyvinyidence fluoride (PVDF), polyether ether ketone (PEEK), polyimides and polysulphones are produced in low volume but are attractive in view of their special properties. These speciality polymers can be used at elavated temperatures upto 300°C. Several engineering polymers have already been introduced in the country. They include PET, PBT, Nylon-6, ABS and (engineering) polypropylene, and they account for more than 50% of the engineering applications realized abroad. Fibre reinforced plastics find applications in oil/gas exploration, construction of biogas, plants and automobiles. However, the main application of FRP has been in chemical process equipment to combat corrosion.

Advanced polymeric composites holds promise for a revolution in structural applications. High performance polymer composites are made by using strong and stiff fibres (such as carbon, aramide, boron, etc.) held in desired orientation and bound with suitable thermoplastic or thermoset matrix materials. The impetus for development of high performance polymer composites was provided by programmes on space vehicles and military aircraft which needed structural components of minimum weight and high strength in prescribed directions. The present combat aircraft use close to 30% composites and this is likely to increase to about 50% in the next generation of combat aircraft. Presently, the use of such composites is growing in applications where performance, rather than cost, is the key criterion. Helmets, body armours, light weight segments of movable bridges, portable rocket launchers are some key examples. High performance composites (such as carbon fibre/epoxy) have great promise in the manufacture of industrial machinery as reciprocating or rotating parts. At present, weight, strength, fatigue life, noise and natural vibrational frequency of metals limits the operating speeds and thus productivity of industrial machinery.

Helicopters provide a most instructive example of the advantages derived by the replacement of metals by composites. In a specific case under study the number of parts got reduced from 11,000 to 1,530 and the number of fasteners from 86,000 to 7,000 by such replacement. There was also a remarkable increase in the reliability of the machine.

Use of advanced composites in automobile sector is presently limited due to an unacceptable balance between processing speed and costs, lack of technology for joining and repairing, long term dimensional stability, etc. However, lower tooling costs, greater manufacturing flexibility, reduction of body parts, reduced corrosion, etc. are definite advantages. Advanced composites have found applications in leaf springs drive shafts etc. and even composite engines have been constructed and tested. In the Indian context, the use of advanced composites in automobiles will however be limited.

The sixties saw the introduction of revolutionary new rigid and semi-rigid fibres based on liquid crystalline solutions. The para aramid poly p-phenyleneterephthalamide fibres obtained by spinning the solutions were introduced by Du Pont in 1971 under the trade name 'Kevlar'. The aromatic substituents in them stiffen the polymer chain. It has a tensile strength of 1400 MPa. The density of p-aramid fibres is about 40% lower than that of fibreglass and 18% lower than that of carbon fibre, which therefore gives it high specific strength. It is also more ductile and has very high thermal stability. This family of fibres is making extensive incursions into aircraft frame materials displacing aluminium alloys in a significant fashion. An airframe completely made of composites has become a reality. The experience gained in the more demanding aerospace field can be put to good use in less demanding applications of the automobile sector. One of the most exciting developments in recent times is the carbon-carbon composite. A typical carbon-carbon composite possesses a Young's modulus of 340 GPa and a tensile strength of 2100 MPa. Thus the composites are stiffer than titanium and stronger than steel. A spectacular feature of these composites is the increase in their strengths as the temperature increases. While most metals and ceramics soften at high temperatures of the order of 2000°C, these composites are stiffer and stronger than aluminium at 20°C.

3 Materials Processing

There is, at present, an increased sophistication in our understanding of the correlation between structure and properties. To reap a harvest of new materials from this knowledge, the crying need is for new technologies; while scientific knowledge permeates rapidly across geopolitical barriers, technologies do not. They are coveted as they determine how rich the nations are. This section describes a few chosen processing technologies which are very promising, some of which are still under development, for the synthesis of electronic and structural materials.

Molecular beam epitaxy (MBE) is an emerging technology. It was invented by Leo Esaki of IBM, USA, in 1970, but it is not yet a production line technology for the manufacture of integrated circuits. It has been perfected in the laboratory, to a high degree, for fashioning superlattices by precise control over the composition of layers that are deposited. It is possible to produce periodic, quasiperiodic and nonperiodic modulations and create hitherto impossible configurations in electronics.

Rapid solidification processing has revolutionised our abilities to produce alloys far removed from equilibrium. It is possible to achieve cooling rates exceeding a million degrees Kelvin per second with relative ease. The materials thus processed are free from segregation and display fine microstructures. In addition it is possible to obtain, with a suitable combination of alloying elements, metastable crystalline phases. The most promising applications are in the area of light weight aluminium-lithium alloys and aluminium-transition metal alloys for high temperature applications. In ferrous materials the magnetically soft Fe-Si-B amorphous alloy and the magnetically hard Fe-Nd-B crystalline alloys can be processed using rapid solidification.

Another important processing technique is called directional solidification. Its application to turbine blades is well known. Since the grain boundaries are aligned parallel to the applied uniaxial stress, in directionally solidified alloys, creep due to grain boundary sliding is inhibited. Further refinement of the technique leads to single crystal turbine blades. India has made headway in mastering some of these intricate technologies.

Superplastic forming is yet another advanced technique which can be used for designing complex shapes with remarkable chemical and microstructural homogeneity. When used along with diffusion bonding, this technique promises greater structural reliability in airframes made with aluminium and titanium alloys.

Powder processing of metallic and ceramic materials has witnessed several important developments. Hot isostatic pressing, or hipping, as it is more commonly known, can be used to form powders into predetermined shapes. It can also be used to heal defects in precast components as well as to regenerate old turbine blades which might have developed porosity.

With the increased prominence of composites we are likely to see automated composite fabrication involving tape and ply laminating, pultrusion, thermoforming and filament winding.

The use of poweful lasers, for annealing semiconductors, glazing metallic surfaces etc has been growing unabated. The field of surface engineering would imbibe laser applications along with the use of techniques like ion implantation.

The use of non-destructive evaluation is widespread in the characterisation of metallic components. The inherent brittleness of ceramics makes it imperative that reliable techniques are developed for their non-destructive testing. Considerable promise is found in techniques such as acoustic emission and laser holography.

Computers are perceived to have a greater role in processing technologies of the future. Whey they are coupled with developments in lasers and sensors, they may revolutionize the foundry and forge plants of the future. There is considerable work currently under way on the development of expert systems and artificial intelligence, to evolve a new approach to materials manufacturing.

4 Key Materials for Intensified Programmes: A Recommendation

The overview essays in the previous sections point to the following: in about 15 years from now, several of the materials which are being investigated in the laboratories today will reach a stage of application and marketability in advanced countries. It would therefore be advisable that R&D efforts are intensified in our country in these materials. Such a strategy provides a salutary advantage and enables us to share with the industrially advanced countries the benefits derived from programmes on modern materials. A sector-wise summary of the key materials is given below.

4.1 Electronic Sector

We noted that the two semiconducting materials of promise and prominence in the coming years are amorphous silicon and gallium arsenide. However, it does not mean that crystalline silicon would disappear from the scene; but the indications are that, to a large extent, the areas of 'slow' and 'fast' electronics will be dominated by amorphous silicon and gallium arsenide respectively. The present level of activity in India in these areas is on a rather low key. There are only four laboratories working on amorphous silicon, largely with academic interest. An effort which is at least 20-25 times the present level would be needed to keep amorphous silicon activity on par with other advanced countries like Japan. It is of seminal importance to take a pragmatic approach, and put products based on new semiconductors into the market, without waiting for the 'perfect' things to roll out of the factories. We should note in this context that amorphous silicon solar cell was introduced in consumer electronics in Japan even when the efficiencies achieved were only 6-7%. It is now known that large panels (greater than 100 cm^2) of amorphous silicon with higher efficiencies (10%) can be easily fabricated. Programmes which explore the complex area of device physics and the development of amorphous silicon electronics should be emphasised.

Gallium arsenide has been a totally academic activity and that too in only a couple of institutions like TIFR and IISc. While arsenic is produced by the Nuclear Fuel Complex, production of modest quantities of gallium has been reported from Mettur Chemicals. It is learnt that gallium is available in significant quantities in India. Thus with the availability of raw materials within the country, gallium arsenide electronics should be given a thrust, keeping in view the enormous advantages they bring to a variety of sophisticated electronic devices such as HEMTs, by the end of the century.

III-V semiconductors based on gallium arsenide are essential for the development of light emitting diodes. The development of these materials involves a variety of crystal growing technologies including liquid and vapour phase epitaxies. Projects related to light emitting diodes must be strengthened as part of an integrated programme on gallium arsenide electronics.

4.2 Communication Sector

Metal wire based communications will most likely get phased out by the end of the century in advanced countries. The advantage of having fibre optic communication in India are immense. Since the population is largely rural, and based in a dense network of villages, optical communication becomes necessary from the sheer volume point of view. An immediate and intense R&D programme related to optical fibres must be undertaken to be able to cope with the increasing demand of communication network. While the basic science related to silica based fibre optics is known, drawing fibres of ultra-high transparency, generating radially graded index in the fibre and cladding the fibres with lower index materials require highly sophisticated technology. Preparation of high purity silica for fibres is being accomplished through sol-gel technique using hydrolyzable organic silicon. The preparation of the organic silicon (tetra ethoxy silane) can be accomplished in industries presently manufacturing elemental silicon such as Mettur Chemicals. Optical fibre communication also requires suitable light sources and presently the best suited materials for the purpose are provided by the GaAs-based III-V semiconductors, referred to in an earlier section, and should constitute a part of GaAs electronics activity.

Many of the electronic materials required for the television industry are at present imported. One category of electronic materials for this industry is the phosphors which are based on II-VI semiconductors like zinc sulphide. While the scientific work reported from India on the optical studies of II-VI semiconductors is itself quite insignificant, reports related to indigenous technology development of phosphors are virtually absent. It is therefore to be emphasised that a programme for the development of phosphors are extremely urgent. In fact, it would be appropriate to have an entire laboratory just on II-VI semiconductors, where the research work carried out is taken all the way from the laboratory table to the industrial production units.

Another class of materials where a timely emphasis can result in significant economic gains, is the class of amorphous magnetic alloys, based on Fe-Ni system containing silicon, boron and phosphorus. Amorphous alloys are a recent discovery and, as pointed out earlier, are produced by ingenious methods of rapid quenching, a technology which is well within the capabilities available in our scientific institutions. Development of rapid quenching technology will have spin-offs of great value. It will undoubtedly lead to the development of new alloys, impossible to make from conventional methods due to kinetic constraints. Communication systems require these magnetic alloys for their recording heads and also in their transformer cores.

Opto electronic materials like lithium niobate, KDP, ADP, BANANA, PZT, PLZT needed both in defence and civilian applications in a variety of electronic control systems are presently entirely imported. The demand for these materials in the next fifteen years will continue to increase. The technology needed is only a variant of the non-conventional crystal growing methods. It is, in fact, inconceivable why we have so far not exploited the indigenous capability in making these materials. An industrial complex dedicated to carry out the entire spectrum of R&D work, and to produce indigenous single crystals of quality, required in the electronic control systems, is an urgent national imperative.

4.3 Transportation Sector

It is convenient to consider requirements of ground transportation and aviation separately. India is committed to expanding its railways and public transport system. Correspondingly, there has been a large increase in the number of automobiles and almost an explosion in the use of two wheelers. Such a large volume of production entails enormous quantities of materials. In earlier years ordinary steel and cast iron were used. There is now a shift towards high strength low alloy steel, aluminium and fibre reinforced plastic. The national effort in developing the technologies required for the use of these materials is already at a high level. The R&D centres of Steel Authority of India Limited at Ranchi and Tata Steel at Jamshedpur have pioneered the use of high strength low alloy steels in India. There is a clear case for intensification and expansion of these efforts, as these steels reduce weight and improve fuel efficiency.

The possibility of building gasoline and diesel engines from ceramics has been pointed out in an earlier section. It is likely that within the next decade there may be a revolution in automobile engines with the deployment of advanced ceramics such as silicon nitride. Research effort on structural ceramics in India is still at its infancy. A strong emphasis in research and development of structural ceramics is required. The stringent requirements for materials to be used in airplanes and spacecraft have provided a strong driving force in materials science and engineering. The remarkable developments in advanced composites are entirely due to this stimulus. While the National Aeronautical Laboratory (NAL) has played an important role in the development of fibre reinforced plastics, there is negligible Indian competence in the use of kevlar and carbon-carbon composites. The preparation of these materials, the processing technologies associated with them, and their nondestructive evaluation call for a strong base of research in composites. Structural design using composites and materials design are intimately related. In many situations, the mere replacement of a metal frame by a composite frame may not offer much of an advantage. However, redesigning frame, taking advantage of the anisotropy of the composite, can tilt the balance. This calls for an interdisciplinary R&D team involving structural engineers and materials scientists. One of the alloys of major interest is aluminium-lithium. Over the past few years, research teams in India have built up strong competence in processing this alloy. There is a clear need to test certify this alloy at an early date.

The thrust-to-weight-ratio of the jet engines being developed for use in the next generation of military aircraft are expected to exceed 10:1. Developments in casting technology such as investment casting, directional solidification and coatings make these advances possible. The Defence Metallurgical Research Laboratory (DMRL) has made considerably headway in these technologies. Current interest revolves round the development of ordered intermetallics such as nickel-aluminide and titanium aluminide. A small addition of boron improves the ductility of these alloys. The changes in the grain boundary structure is a challenging problem in basic research. Indian contributions to the study of the atomic configuration at grain boundaries are well recognised: including the research initiative been recently launched by the Department of Science and Technology. Additional teams have to be involved in this effort.

A large variety of industrial metals, alloys and ceramics employed in this sector require the use of industrial lasers. In fact, industry should adopt processes like laser cutting, laser annealing, laser glazing etc. on priority in order to inject a new culture of advanced technology. CO_2 or Nd-YAG are the principal power lasers used at present. Even the big industries and laboratories of the country do not appear to have adopted the use of power lasers, except for one or two places like DMRL & HAL. It is very essential that a substantial amount of effort and money is invested for developing the laser industry. Development of ruby lasers and YAG based lasers of trivalent rare earth ions should be possible within a short time given the required emphasis and support. Similarly special efforts should be made to develop high power CO_2 lasers within the country. Some progress in this direction appears to have been made at CEL. With the inception of the

Centre of Advanced Technology at Indore, this activity will get a further impetus.

It may not be far fetched to visualise introduction of high speed levitation transport in our country particularly for inter-city transportation. The discovery and the current feverish activity (even as this report is being completed, there are reports of the discovery of 237 K superconductor in the USA) related to superconductors make it appear distinctly possible that India could be among the leading countries in the development of levitation transportation. A few Indian scientists have made very significant contributions to the chemistry of mixed valence oxides. The technology related to fabrication of high power magnets is also available in the country. The level of metallurgical and materials science and technology in the country can certainly meet the challenge of providing cladded superconductor wires and strips. The creative engineering needed in realizing levitation transport is again available in the country. Since the Indian Railways are the second largest in the world, a combination of the technical advantages and the sheer pride of pioneering the new technology should make this a symbol of Indian achievement by the end of this century, if the required inputs are made available immediately.

4.4 Energy Sector

The energy sector is the one which demands attention, and even gets it, from an otherwise slumbering society. Much is currently being done to meet the energy crunch with massive investments in atomic and hydroelectric projects. This report will not touch upon these specialised areas. The emphasis here is on a strategy based on new materials for harnessing the inexhaustible source of solar energy. The country is blessed with abundant sunlight and, as pointed out earlier, both photovoltaic and photo-electrochemical routes can be employed for the purpose. In a previous section, the merits of amorphous silicon have been emphasised in this context. If the nation is very pragmatic, rural and urban electrification (for providing lighting and hot water) in future may be provided entirely through the use of solar panels, both photovoltaic and thermal. Such an approach will save not only the conventionally generated power but a whole lot of other expenditure involved in conveying the power up to the user point. The hydrogen route to solar energy is very strongly recommended as a supplement to photovoltaics. The present programmes of DNES and other state and private sector programmes in this direction should be given all the possible support. R&D effort for making new alloys (like La-Fe systems) required for hydrogen storage and transportation, should also receive immediate attention. Here again waiting for the ultimate to happen in the laboratory, and for the best products to roll out of the factories before we begin to use them, could be an unwise policy. We should transfer the achievements of the laboratory for the use of our society without much delay and continue with improvisations. It should be easy to inculcate a culture of H_2 usage similar to that of LPG in our country. Work related to development of fuel cells based on zirconia as solid electrolyte should be supported fully so that electrically run automobiles become a reality by the year 2000. Zirconia is our blessing since we have it in abundance in the country. We may note that automobiles free of pollution causing exhausts is an important need of the future and electric automobiles are therefore very essential. Thus, by the end of century, we should be looking for strong R&D programmes devoted to H_2 economy based on solar energy programmes. A centralised source of power, which is far less hazardous than even the hydroelectric sources (impoundment of large volumes of water have caused disastrous quakes in the past) is the magnetohydrodynamic power station. The new superconductors should generate a sense of well-founded optimism in this context. This is again an area where our country has a bright chance for a claim to leadership. Programmes related to MHD must be supported with this futuristic point of view.

4.5 Other Sectors

An important need of other industrial sectors is a large variety of sensor materials. There are quite a few sensor materials options and all of them can be made in the country with indigenous knowhow. The Japanese, reportedly, get all their sensors made in about 400 small scale industries dedicated to such manufacture. India should also adopt the same approach. Materials like zirconia, zinc oxide, chromia, iron oxide, titania required for the purpose are all available in the country.

5 Conclusions and Summary of Recommendations

The materials in use in India are numerous. This report emphasises only a few select items which deserve immediate attention, as they are the most likely to be key materials by the year 2000 (Table 8). The Tables 9-10 present programmes related to electronic ceramics in Japan and USA. If the

Table 8

Summary of Recommendations

Materials	Area of projected applications	Current status and *support recommended*
I Electronics Sector		
1 Amorphous silicon	'slow' electronic devices: reprography (also relevant for energy sector: Photovoltaics)	very low key and largely academic activities; *20-25 times the present level of funding should be invested*
2 Gallium arsenide and related III-V semiconductors	fast electronic devices computers: specialised photovoltaic applications, light emitting diodes and other solid state applications	very little effort; *A national laboratory fully dedicated for the purpose should be established*

Table 8 (*Contd.*)

Summary of Recommendations

Materials	Area of projected applications	Current status and *support recommended*
II Communication Sector		
3 Quartz fibres	Optical transmission	fibres have only been bought in trial applications; *activity should be initiated on a large scale for silica fibre preparation starting from organic silicon by sol-gel route. R&D on oxide and halide fibres should be simultaneously emphasised*
4 III-VI Semiconductors	phosphors for TV industry	virtually fully imported; *entire gamut of of II-VI semiconductors to be developed in a dedicated laboratory*
5 a-magnetic material of Fe-Si-B-C; opto-electronic crystals;	recording heads transforms cores, etc.	fast quenched alloys are only an academic activity at a few centres

Table 8 (*Contd.*)
Summary of Recommendations

Materials	Area of projected applications	Current status and *support recommended*
6 Fe-Nd-B permanent magnet	Motors	Isolated effort; *R&D on rapid solidification of these alloys can be initiated*
7 KDP, ADP, BANANA, PZT, PLZT, KLN, LN, etc.	signal modulation and control electronics	rather isolated efforts and mostly imported; *a national single crystal facility to be established to meet the entire gamut of single crystal materials*
III Transportation Sector		
8 Aluminium alloys	Mopeds, automobiles, trains, aircraft	well developed systems are available; *necessary to intensify research on aluminium-lithium alloys*
9 Intermetallic compounds	engine material	*new technology needs to be developed*

Table 8 (*Contd.*)
Summary of Recommendations

Materials	Area of projected applications	Current status and *support recommended*
10 Toughened zirconia, silicon nitride	automobile engines; tools	*intensive programmes have to be initiated*
11 Kevlar and carbon-carbon composites	Advanced composites for initial deployment in aircraft and later expansion into less strategic areas	expertise in fibre reinforced plastics exists in the country; *activity on advanced composites needs to be strengthened*
12 YAG and glass matrix rare earth ion lasers	laser machining laser annealing laser cutting, etc.	virtually non existent, even its use appears to be very limited; *a.crash programme for the development of industrial lasers is recommended*
13 Superconductors: novel valence fluctuating oxide	levitation transport (also relevent to other sectors like in energy for magnetio-hydrodynamics) and in health sector for magnets used in whole body scanners	scientific knowhow for the preparation available in the country but no action in the direction of exploiting it for definitive industrial applications; *highly recommended as an area which promises leadership opportunities*

Table 8 (*Contd.*)
Summary of Recommendations

Materials	Area of projected applications	Current status and *support recommended*
IV Energy Sector		
(1a) Amorphous silicon	referred to earlier in electronics sector	*heavy investment is recommended*
14 Hydrides	hydrogen from photo electro-chemical cell used in direct burning and in fuel cells	many photo electro chemical cell material investigated and developed in the country, hydrogen storage particularly in LaFe type of alloy not being investigated; *R&D programmes to be intensified with much larger level of funding than now*
V Other Industrial Sectors		
15 Sensors Semiconducting oxides transition metal oxides and zirconia	Oxygen, humidity, toxic gases, etc. detection, monitoring and measurement	knowhow available in the country and scattered in a variety of research centres; *all types of sensors to be developed in small scale industries like in Japan*

Table 9

Electronic ceramics in Japan

Product	1982 Sales (million of yen)	Increase over 1981	1983 Sales (million of yen)	Increase over 1982
IC Packages	85500	+ 25.7%	101800	+ 19.1%
Ceramic	4570	+ 1.8%	5000	+ 9.4%
Substrates	89280	+ 10.8%	107060	+ 19.9%
Capacitors				
Piezoelectrics	30822	+ 6.0%	45690	+ 9.8%
Thermistors	15849	+ 13.0%	19318	+ 21.0%
Varistors	7726	+ 5.0%	9357	+ 21.0%
Sensors (ZrO_2)	+ 38.0%	5690	+ 22.0%	
automotive				
industrial				
Ferrites				
soft	59594	- 6.0%	69500	+ 16.0%
hard	36999	- 6.0%	43300	+ 17.0%
Cutting Tools				
ceramic	1072	- 18.7%		
cermet	4412	+ 17.4%		
coating	8294	- 7.4%		
Wear Resistant Alumina	19568	+ 17.0%	20214	+ 3.0%
Honeycomb ceramic	9300	+ 30.0%	10700	9.0%
Bioceramics	1780	+ 132.0%	2700	+ 51.0%
Total	318372		440542	+ 38.3%

Table 10

Growth of electronic ceramics in U.S.

	1983	1982	+/-9%
	(Thousands of Dollars)		
Semiconductors			
Metal oxide varistors and other semiconductors	271136	170260	59.2
Magnetic bubble memories	18864	50321	(62.5)
Solar cells LEDs, and other photoelectric cells	244943	325369	(24.7)
Ferrites			
Microwave	139715	119808	16.6
Hard and soft	79253	66486	19.2
Resistors			
Fixed (incl. evaporated film)	188714	176822	6.7
Thermistors and varistors	23016	24280	(5.9)
Capacitors			
Fixed	44798	45968	(2.5)
Chip	107738	82247	31.0
Leaded (radial, molded and dipped; axial, molded)	175427	167855	4.5
Glass and Conformal (and other leaded)	122875	85952	42.9
Mica, Ceramic and Glass variable	13007	15512	(16.1)
Standoff and two terminal	4176	6088	(31.4)
RFI and EMI ceramic filters	80381	62154	29.3
Ceramic bypass and feed through filters and others	21659	9029	140.0
Piezoelectrics			
Electromechanical filters	12276	14183	(13.4)
Electromechanical crystal filters	42287	47220	(10.4)
Crystals	81840	95232	(14.1)

money invested in these countries is an indication, the tasks ahead are frightening complex. Unfortunately, a reliable survey of the country's needs is not available in order to make comparisons. But the clear message from these tables, and from other published literature on the materials for the year 2000, is that a comparison between the domestic and foreign cost is unwise because such a comparison would unduly distort development decisions. Our country needs materials and we have to make them. The alternative of always buying finished products from other countries is simply not affordable.

Appendix-2

Processing Facilities for Special Alloys at Mishra Dhatu Nigam (Midhani) Limited, Hyderabad

(Total value: more than Rs 100 crores)

I *Melting*

1. Air arc furnace (5T)
2. Vacuum induction refining furnace (5T)
3. Air induction melting furnace (1.5T/2.5T)
4. Vacuum induction melting furnace (1.5T/2.5T)
5. Vacuum arc remelting furnace (4T max. and O 500 mm max.)
6. Electroslag refining furnace (5T max. and O 600 mm max.)
7. Vacuum arc remelting furnace for titanium
   (6.5T max. and O 860 mm max.)

II *Forging*

1. 1500T hydraulic press with two integrated rail-bound manipulators
2. Electro pneumatic hammers (1.5T and).75T)
3. Heating furnaces

III *Powder Metallurgy Shop*

1. Powder pressing press - 600T
2. Bell sintering furnace (3 nos.)

3. Mo sintering furnace
4. Recrystallisation furnace
5. Manual swaging machine (2 nos.)
6. Continuous swaging machine (5 nos.)
7. Wire drawing machines (9 nos.)

IV Hot rolling, cold rolling, cold drawing equipment, heat treatment, pickling, machining, conditioning facilities and modern quality control equipment.

Appendix-3

Processing Facilities for Special Materials at Nuclear Fuel Complex, Hyderabad

(Total value: Approximately Rs 25 crores)

I Production facility

1. Solvent extraction
2. Chlorination at low temperature in monel and inconel vessels and glass/ quartz vessels
3. Distillation in glass columns
4. Hydrogen and carbon reduction of oxides in metal vessels
5. Vacuum melting/casting of low melting metals such as Pb, Sn, Zn, Sb, Cd, Bi, Te, Se, In, Mg
6. Vacuum distillation of low melting point metals mentioned above using glass, quartz and metal containers
7. Zone refining unit using resistance heating in glass and quartz tubes
8. Electro-refining-aqueous and fused salt bath
9. High vacuum sintering and annealing (upto 2200C)
10. Electron beam melting and refining (60 KW)
11. Hydriding/dehydriding equipment for reactive refractory metals
12. Magnesium shots making by rotating electrode process
13. Extrusion presses and annealing furnaces
14. Tube drawing and testing facilities

II *The processes used for extraction and purification of various pure materials*

Materials	Process used
1. Tantalum and Niobium	Solvent extraction, vacuum sintering electron beam melting
2. Magnesium, Zinc, Tellurium	Vacuum distillation
3. Bismuth, Cadmium, Zinc, Tellurium	Zone refining
4. Tin, Indium	Electro-refining
5. Antimony	Chlorination, distillation, electo-refining
6. Selenium	Distillation, vacuum melting and casting
7. Powders of zironium and titanium and their hydrides	Hydriding and high vacuum dehydriding
8. Gold, Silver and their salts	Chemical processing.

2

Photonics

If, a hundred years ago, the most erudite and versatile scientist of the time had been asked the question "what area of physical science would dominate the scene in the 20th century?", whatever he would have said would have proved wrong since, by the 1880s, radioactivity had not yet been discovered, nor X-rays, nor the electron, nor the nucleus; electromagnetic radiation had not yet been produced in the laboratory, neither quantum mechanics nor relativity was known, let alone the field of elementary particles. If, inspite of such a historical precedent, a similar question is asked today, about the 21st century, perhaps one can say with a good deal of confidence that this century would be the era of 'photons'.

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2

Photonics

Preamble

The Science Advisory Council to the Prime Minister (SAC-PM) set up a Task Force to prepare a report on Photonics, highlighting the state-of-the-art projections for the future in this area, in the Indian context.

The present report has been prepared by the Chairman taking into account the deliberations of the Task Force and the detailed comments of individual members. While the members placed varying emphasis on the different aspects of photonics, they were unanimous in recommending the action points mentioned here. Although there may be certain programmes already going on as part of the activities of certain Departments of the Government of India, the Task Force has not specifically commented on them.

The preliminary note prepared by Prof B V Sreekantan ''21st Century: The Photon Era'' served as a useful starting point for the discussions of the Task Force. ■

1 Introduction

Photonics, the science of coherent beams of photons, is rapidly emerging as a field with a large number of applications that far surpass the already remarkable achievements of electronics. More specifically, photonic applications may be considered under three categories:

- Communication systems
- Lasers
- Photonic computing

The scope of applications of Photonics as perceived today is summarised in the following paragraphs.

2 Applications of Photonics

2.1 Communication systems

Light energy in coherent form can transmit information along an optical fibre. For its economic exploitation one needs to (a)improve the data transmission rate and (b)increase the distance over which the information-bit-stream is transmitted before a repeater is needed. The *Fig. 1* illustrates the dramatic impact of this technology on commu-

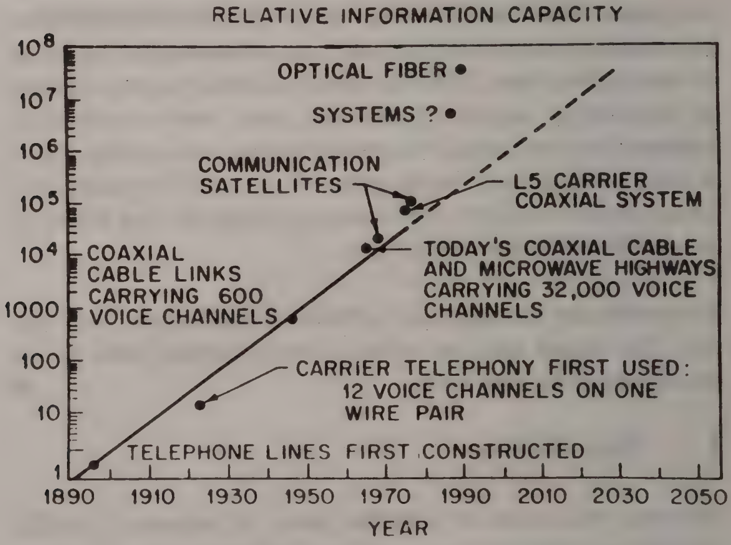

Fig. 1 The dramatic progress in communication systems since the first telephone channel of 1876.

nication systems since the first telephone channel in 1876.

The developed countries are already making massive inputs in optical communications technology. The present state of applications may be summarised thus:

- It is now established that for large volume traffic densities and long hauls in telecommunication systems, optical communication is economically more attractive than satellite, microwave and coaxial cables systems. Besides, it is totally free from electromagnetic disturbances.

- With the explosive growth of informatics, the trade and commerce is becoming increasingly dependent on highspeed data acquisition and transmission. For this purpose, massive inputs are being made on optical communication in developed countries (NTT of Japan plans to create a $ 120 billion market over the next 10 years for suppliers who want to participate in the development and implementation of this system).

- The technological targets both of the Japanese Information Network System (INS) and the West's Information Services Digital Network (ISDN) are to provide voice and data transmission, highspeed facsimiles, database services and advanced telephone features like voice, message storage and retrieval, touch-button data entry and call recording and screening. To achieve this, telecommunication research today aims at providing a socket in every home and public place where a person could plug a telephone, television set, computer and other such instruments to instantly receive or send voice communication, video images or highspeed data.

The fibre optics communication technology holds several advantages in the national context such as:

- Our industry today needs reliable data at ever increasing speeds to survive the intense competition within and outside the country. This can be provided by integration of computers with communication - something which fibre optics technology alone can provide.

- We only have 2.5 million telephones in our country; this works out to only 0.3 telephone for every 100 persons. In an advanced country like Sweden there are 85.6 telephones per 100 persons. Even to provide 25 per cent of the households with telephones in a reasonable span of 5-7 years we need 30 million more telephones to be installed. This can only be achieved by optical communication technology.

- ISDN/INS technology offers several advantages to our farmer. Plans of action during floods and droughts can be instantly communicated. The quick availability of data regarding the price of the produce prevailing at other market centres would also be of great help to the farmer.

2.2 Lasers

Although lasers play the key role in photonic communications, they have applications over a far wider field.

Some of these applications are:

- Scientific applications in instrumentation etc.
- Medical and surgical uses
- Military applications
- Industrial processing
- Remote sensing

It is worth emphasising that, apart from the developed countries, China too is going in for laser technology in a big way. In the Chinese system, R&D laboratories are backed up by production centres. For India, apart from the communications aspect, the other societal benefits provided by lasers are in health care and industry. The military applications, of course, have great relevance to the country's defence.

This area of photonics can be broadly divided into two groups over which programmes can be pursued more or less independently:

- Lasers and their applications
- Lasers in information technology

2.3 Photonic computing

The use of photons, instead of electrons, in transmission or storage of information in a computer is an emerging area that is still R&D intensive. It is, however, widely recognised that a photonic computer, when it is made, will have a number of advantages over its electronic counterpart in terms of speed, low cross talk and parallelism. However, associated practical problems may take several years to resolve before optical computers can truly be made viable.

3 Recommendations

Several time-bound goals can be identified within the Indian context. Some examples are given below.

- All new telephone and other communication services should switch over to optical fibre based systems in a phased manner so that, by the year 2001, the national communications system will be fully photonic, and of international standard. This could be part of an Integrated Information Network (IIN) programme to make the country self-reliant and self-sufficient in producing materials, devices, systems hardware and software. To begin with, a Technology Demonstration Project, to demonstrate the capability in the state-of-the art fibre communication system, should be set up with well-defined goals and time frames. Briefly, this would involve development of single mode fibres, development of laser sources (DFB and DBR), electro-optic modulators, optical bistability devices etc., as well as studies on system engineering.

- In the field of lasers we should aim at developing all known important lasers like Nd: YAG, Nd: Glass, Dye, CO_2, N_2 etc. Development of materials and components should proceed side by side. For example, work on laser components must be accompanied by work on precision mechanical components, laser crystals and glasses etc. Work on Laser instrumentation, including medical as well as industrial lasers, has also to be simultaneously undertaken.

- This is the right time to start R&D effort in photonic computing. No organisation in the country is, as yet, working in this area but a start should be made, with a group familiar with computer architecture and design working in collaboration with experts in optical, laser and semi-conductor techniques. The aim should be to produce a prototype optical computer by 1995.

4 Implementation

Work in photonics encompasses diverse areas of R&D such as new computer architectures, development of new materials and devices like optical integrated circuits, etc. It is also essential to back up these R&D efforts by fully operational production facilities. Specifically, the following action points are suggested:

4.1 Programme for optical communication systems

This programme should include the following areas of development:

- Materials
- Devices
- Optical information transmission and processing systems
- Integrated system prototype
- Software

If such a programme is successfuly then India could undertake business in optical communication systems worth several millions of rupees every year.

4.2 Programme on Lasers and Their Applications

Under this programme we should concentrate initially on:

(a) Development of all important known lasers, like Nd: YAG, Nd: Glass, Dye, CO_2, N_2, Copper, Gold, Ar, Kr, He-Ne, Excimer, He-Cd.

(b) Development of all related materials and components. These should include:

- Material of laser windows, e.g., ZnSe,
- Laser crystals and glasses, e.g. Nd: YAG, Ruby, Nd: Glass,
- Nonlinear crystals, e.g. $LiNbO_3$,
- Laser components, e.g. laser mirrors, lenses, windows, electro-optic modulators etc.
- Precision mechanical components.

(c) Development of laser instrumentation for medical and analytical applications

(d) Development of industrial lasers

4.3 Programme on Lasers in Information Technology

Under this programme, the following should be pursued in the first phase:

- Development of semiconductor lasers and detectors
- Development of optical fibres and associated technologies
- Optical communication system development
- Optical information processing
- Holography
- Optical data storage

4.4 Programme on Photonic Computing

In the area of photonic computing it is felt that a group which is already familiar with computer architecture and design is best suited to organise work in this area. Also, the hardware realisation of optical computing elements would need the experience of an optical, laser and semiconductor laboratory. It is therefore suggested that a study group be first formed for assessing the technology in this area and to suggest plans for implementation. The group may consist of scientists from TIFR, IISc, SPL, BARC, IRDE, the IITs and other academic institutions working in the area of computer architecture.

4.5 Logistics of Programme Implementation

There is a danger of spreading the effort too thinly over a large number of groups working below threshold and in a mediocre way. One view is to have a dedicated national laboratory while the other view is that a single monolithic institution on photonics cannot yet be justified.

A National Coordinating Committee on Photonics (NCCP) should be set up, with necessary powers delegated to it, to draw up a coordinated, goal-oriented time bound strategy on photonics. The NCCP should begin by setting up multi-agency programmes that make use of the existing talent and facilities available at a number of institutions in the country (such as IISc, TIFR, BARC, SPL, CGCRI, IITs, IRDE etc.), and also involve the considerable expertise available from NRIs abroad.

5 Conclusion

It is the unanimous view of the Task Force that there should be strong emphasis on the nation going into photonics in a big way, and with the same dedication with which it launched its atomic energy and space programmes.

Appendix-1

Note on '21st Century: The Photon Era'
Prof B V Sreekantan

Synopsis

If, a hundred years ago, the most erudite and versatile scientist of the time had been asked the question "what area of physical science would dominate the scene in the 20th century?", whatever he would have said would have proved wrong since, by the 1880s, radioactivity had not yet been discovered, nor X-rays, nor the electron, nor the nucleus; electromagnetic radiation had not yet been produced in the laboratory, neither quantum mechanics nor relativity was known, let alone the field of elementary particles. If, inspite of such a historical precedent, a similar question is asked today, about the 21st century, perhaps one can say with a good deal of confidence that this century would be the era of 'photons'.

Photons will dominate not only in the applied fields but also in the field of pure sciences, especially astronomy, where technological developments of the current century have opened up all the windows in the electromagnetic spectrum for observation. So far one has had only a glimpse of the types of phenomena that are taking place in the vast universe out there. With the space telescope and the variety of instruments that will go on space platforms, and the future satellites, not only will long standing problems in astronomy and astrophysics be solved, but lot of new physics will emerge through the study of phenomena that take place in environments that can never be produced in the laboratory.

Coming to the more mundane aspects, there can be no question that the laser generated coherent photon beams will dominate the scene of human activity in peace and war. Lasers have entered every field of scientific and industrial activity. The most powerful lasers, of energy 10^6 - 10^9 joules, are serving the needs of laser fusion attempts, isotope separation, production of high temperature plasma and so on. The medium power lasers, of 10^3 - 10^6 joules, are being used for machining, welding, annealing trimming, melting etc. The low power lasers, in the range 10^0 - 10^3 joules, are used for surgery, medical diagnostics, spectroscopic research, pollution detection, ocean illumination, deep sea measurements etc. The very low power lasers

(10^{-1} - 10^{0} joules) have ushered in 'photonics' for optical communication, optical computing, optical VTR, bionics, displays etc., threatening to replace 'electronics' for these purposes.

How is it that 'electronics' is making way for 'photonics' in communications and computer areas? The reason is simple. The electronics-fed society is now thirsting for still higher speeds of communication, greater volume of communication and faster computers with parallel processing capabilities. Electronics has reached its 'physics limits' in terms of speed - the fastest switches being the gallium arsenide devices with switching time of 12 picoseconds. One cannot make the switching any faster by reducing the thickness of the junction layers further, because, the transistor action will just fail. In addition there is the inevitable LCR delay in electronic transmission, which cannot be reduced by further miniaturisation.

The harnessing of the photon beam has:

- the advantage of high speed
- no electromagnetic disturbance (pick up)
- no delays due to LCR
- the advantage of all the special features of optics - focusing dispersion, interference, polarisation etc., which can be achieved through simple devices like lenses, prisms, etalons, gratings etc.
- the capability to very effectively use non-linear optics
- the advantage of being particularly well-suited for parallel processing
- and the most important advantage, of course, is the bandwidth since the frequency corresponding to optical beam in 10^{14}Hz, a factor 10^{4} higher than what has been reached with the highest freqency microwave, ~10^{10}Hz.

To make photonics feasible many important developments have to take place: (a) development of optical fibres, (b) solid state devices as sources, detectors, modulators, and switches of optical beams, (c) integrated electro-optical devices. The requisite developments have taken place over the past two decades, especially in USA, UK and Japan.

While free space transmission of photon beams can be used in special circumstances, as, for example, in integrated electro-optical devices, short haul communication application etc., it is essential to have optical cables for transmission over long distances. Starting with attenuation losses of more than 500 dB/Km in the 1960s, the state of art today with silica fibres

Table 1

Typical characteristics of different generations of fibre optic transmission systems that have evolving/are evolving in the optical fibre transmission market.

Generation	Bit rate	Operating wavelength (µm)	Type of Fibre	Loss (dB/km)	Repeater spacing (Km)	Source-detector	Application
First (1978-82)	34~45 Mb/s	0.85	Multimode (Graded core)	~3	8~15	GaAlAs/Si	Central Office trunking
Second (1980-84)	45 Mb/s	0.85-1.3 0.85	Multi-mode (Graded core)	~1	~30	GaInAsP/Ge	Long-haul Data Links
Third (1982-87)	144~500 Mb/s	1.3	Single mode	~0.5	8>40	GaInAsP/ PINFET	Central Office Trunking-WDM Long-haul, Data Networks
Fourth (1984-90)	>5 Gb/s	1.55	Single mode (SEGCOR)	<0.3	>100	DFB InGaAsP/ GaInAsP	Advanced Long-haul
Fifth (1987-2000)	?	>2	Infrared	>1.01	>1000	?	Superhigh banwith long-haul

From an article by B P Pal and S L Maskara in the August 1986 issue of *IETE Technical Review* has reached the level of 0.2 dB/Km (Appendix-2). Further improvements with new types of fibres made of fluoride and sulphide glasses promise one or two magnitude better performance than what has been achieved with silicon fibres. What this improvement means is simply this: optical fibre communication can now be had from one end of the world to the other without any intermediate repeaters.

Table 1 gives the typical characteristics of the different generations of fibre optic transmission systems that have evolved, and are evolving.

The developments that have also taken place with regard to solid state light sources, switches and detectors, are summarised in Appendix-3.

The most significant development of course is that the solid state semiconductor lasers, operating at room temperatures, are able to lase in the right

Table 2

Details of Kokusai Denshin Denwa (KKD's) third trans-pacific cable

System Length	8000 km (Japan Hawali)
Transmission Speed	269.6 Mb/s
Wavelength	1.31 μm
Opical Source	In Ga As P Laser Diode
Optical Detector	Ge-APD
Sensitivity	<-36.2 dBm
Optical output power	>-4.0 dBm
Jitter	<1 deg (rms)
Lifetime	25 years
Reliability	Note more than 3 ship repairs in service life
Repeater Span	53 km
Submarine Cable	
Maximum Sea Dep	8000 M
Tensile Strength	>10 tons
Weight in Water	0.5 tons/km
Number of Fibers	Six (maximum)
Fibre Loss	<0.4 dB/km

From IEE Communications Magazine, May 1986, Vol. 24, No.5, page 24.

Table 3

Long Distance Optical Fibre Communication Systems

Country & Owner	System Name	Total length (km) (Appx.)	Wave length (µm)	Bit Rate Mbps	Repeate	Expected spacing (Km)	Routes completion data	
US, AT & T	North-East Corridor	600	0.82	90		7	1984	(1) N Y Wash (2) H Y - Bos/ wash - Rich
	California light guide	270-380	0.82	90		7	1984	(1) Sac-Los (2) - Oak
US, Pacific Telesis	-do-	200	1.3	90		7	1985	(1) San Fran.
US, MCI		360	1.3	405		24-32	1984	(1) H Y- Wash
US, AT & T	FT3C-90	50-100	1.3	90	26	1985		(1) Cam- Pleas (2) Chic- Plano (3) Garden- Rego
	FTUE-432	400-800	1.3	432		26	1986	(1) Atl - Green (2) Dal - Hou

Table 3 (*Contd.*)

Country & Owner	System Name	Total length (km) (Appx.)	Wave length (μm)	Bit RateRepeate Mbps	Expected spacing (Km)	Routes completion data	
US, Electra		880	1.3	432	35	1985	(1) Dall - Hous
US, Southern	Light net	8000	1.3	90 (Later 432)	27	1986	In many major cities
Japan, NTT	F-400M	2500	1.3	400	20	1984	Length of Japan
Canada, Sask Tele.	Sask Tele. Broad b.Net	3400	0.84 & 1.3	45	10-30	1984	(1)York- Reg Sasku N.Battle-Mend (2)52 communities
UK, BT		200	1.3	34, 140	8(MM)	Complete	(1) Lond - Birm
	-	170	1.3 (SM)	140 (Later 565)	24	Complete	(2) Manch - Birm
UK, Mercury	Project Mercury	200-300	1.3	140 (565)	21-25	1984	(1) Lond - Birm (2) Birm - Manch

Table 3 (*Contd.*)

Country & Owner	System Name	Total length (km) (Appx.)	Wave length (µm)	Bit RateRepeate Mbps	Expected spacing (Km)	Routes completion data	
Italy, PTC	-	31,65,200	1.3	140	15-30	1984-86	(1) Rome - Pom (2) Milan - Turin (3) Gen - Pisa Livo (4) Rome - Civita (5) Sice - Pale cata
Belgium, RTT	-	28-63 157	1.3	140	13-20	1985	On Four routes
Saudi Arab SCECO	-	70-120	1.3	34.8 (HM)	10-15	Complete	On three routes
International Belgium, Netherlands	-	55-120	1.3	140,28021-30	1985-87On three routes		

From an article by B P Pal and S L Maskara in the August 1986 issue of *IETE Technical Review* frequency range for the lowest attenuation in optical fibres, namely, in the wavelength range 0.83 - 1.6 μm.

The state of the art of the optical communication technology can be seen from the Table 2 which gives the details of the system that is scheduled for completion by 1988 for communication between Japan and Hawaii. This system is being implemented by Kokusai Denshin Denwa Co. Ltd. (KDD). The system length is 8000 kms. The optical cable is designed to withstand a water pressure corresponding to a maximum depth of 8000 meters in the sea. Cable attenuation is as low as 0.4 dB/Km. The system has repeaters every 53 km. The transmission speed is 296.6 mega bits/s.

Table 3 gives an idea of the long distance optical fibre communications systems over the world that have either been already executed or are planned to go into operation over the next few years.

The more recent developments, particularly over the last two years, of a technique of data transmission known as the Wavelength Division Multiplexing, in which ten different lasers with ten different frequencies can be combined using a grating, hold the promise of pushing the speed of transmission further to 20 giga bits/s. What does 20 giga bit/s mean? 140,000 two-way voice conversations, 60,000,000 home computer modems, 6000 TV conferences, 2000 high resolution TV carriers. A technical book of 300 pages, which corresponds to one giga bit of information, can be transmitted in 1/20th of a second with such a system.

Optical Computers

The interest in optical computing is on the increase because of:

- developments in the field of non-linear optics that have made possible optical bistable devices that operate hundreds of time faster than electronic devices

- the optical equivalent of transistor, called "the transphaser", has been developed - here, two optical beams are inputed, one powerful and the other weak through the same semi-conductor crystal. By making small changes in the weak beam the interference conditions in the crystal could be modulated to produce large changes in the transmission of the strong beam with amplification. A family of optical elements have been created which could conceptually form the parts of an all-optical computer - memory elements, differential amplifiers, pulse shapers, limiters, optical triodes and logic elements. Prisms and birefringent devices can also be put to novel use

- the features that make these devices most attractive are:

  (a) extremely large bandwidth $>10^{13}$Hz
  (b) ultrashort switching time $<10^{-12}$s
  (c) capability for parallel processing
  (d) ability to process light directly
  (e) low power requirements

- two dimensional arrays of bistable optical elements have made image processing simple

- advantages of fan-in and fan-out of the binary optical logic gates

- advantages of orthogonal polarisation of light to represent true/false states of a logical variable

- two beam coupling in non-linear optical materials can be used to perform optical logical operations via non-resonant structures

- feasibility of using Fradkin gates which perform theoretically dissipation free logic.

For more information, please see the 15 May 1986 issue of *Applied Optics,* devoted largely to Optical Computing, and the August 1986 issue of the *IETE Technical Review.*

The Indian Scene

What has been described above is the world scenerio in a nutshell. What is the situation in India? This is very well described in the paper of N B Chakrabarti (see Appendix-4).

The Indian situation is, actually, absolutely dismal. The integrated effort of all the institutions (Appendix-5), that are in my opinion operating at sub-critical level, is perhaps less than 0.1% of the world effort - especially when compared to USA and Japan. Clearly in the institutions cited above there are individuals who are keenly interested in pursuing this field and who can contribute very significantly if there is a well planned national effort.

The first question that arises is - Should opto-electronics be a priority area for our country? Does it matter if we ignore this field altogether till we are able to find the necessary resources? Should we just import the technology?

Well, what is absolutely clear is, whether we like it or not, this field of opto-electronics is going to dominate all walks of life. Since, as a country, we do not believe in living in isolation, if we do not wake up now and become self-reliant, we will end up (as has been our case with electronics) being at the receiving end of obsolete or second-hand technologies from other countries. At this stage it is worth looking at the Appendix-6 which gives the scenario in Japan, where, recognising the potential of this field, a new institute for opto-electronics was set up as early as 1981, specifically to take a lead in this area.

The most attractive feature of 'opto-electronics' is that it is a highly interdisciplinary area, the pursuit of which can result in substantial development is several major area of science and technology. These include (a) solid state physics, (b) electronics, (c) materials, (d) optics, (e) glass technology, (f) computer science, (g) systems engineering, and (h) theoretical research especially in the fields of non-linear optics, parallel logic, gate arrays, optical processing techniques, etc.

While one should take cognisance of the very low level of activity in India, one need not get unduly discouraged by it since the potential for rapid take off in all the related areas exists. When the country launched into the atomic energy programme in the late forties, the situation in the requisite technologies was not very different from what it is today in respect of opto-electronics.

What should be done? In my opinion, the first thing is to set up a 'task force' consisting of not more than sixscientists/technologists charged with the following tasks:

- make a technical assessment of the world scenario and identify the specific areas of R&D that India should take up immediately - development of III-V compounds, fabrication of optical fibres, laser diodes, detectors, etc.

- make a critical survey of the strengths and weaknesses of the institutions that are currently engaged in these allied fields of activity, and identify individuals and other institutions where goal oriented R&D can be initiated and monitored under fixed time targets.

- make a survey of the country's requirements in the areas of optical communications and optical computers, taking into account the plans that agencies like P&T, ITI and Defence organisations may already have.

- establish contacts with Indian scientists outside the country and explore how their expertise can be profitably utilised.

- arrange to send young scientists and technologists to specific centres for short and long terms to acquire the necessary expertise in areas which cannot be taken up immediately in the country itself.

- work out the involvement and relations with the relevant government agencies like the Department of Electronics, Communications, S&T, Defence, the public sector and private undertakings in the relevant fields - Semiconductor Complex, BEL, ECIL, etc.

- prepare the budget - immediate and long term and staff requirements, equipments, etc.

Appendix-2

Low Loss Optics Fibres Annexure from Prof Sreekantan's note on the Photon Era

The proposal of using cladded glass fibre for optical transmission was made almost simultaneously by Kao and Hockham in England and Wertz in France in the year 1966. While the attenuation in ordinary window glass of that time was of the order of 10^5fB/km, good quality glass had 500 dB/km. The attenuation was essentially a function of the impurities which had to be reduced (particularly OH ions). By 1970 the loss was brought down in silicate glasses to 17 dB/km by Corning Glass in US at $\lambda = 0.6328\ \mu m$. By 1979, the loss was brought down further to 0.2 dB/km at $\lambda = 1.55\ \mu m$ and in 1982 the loss figure stood at 0.15 dB/km.

New developments are now taking place with sulphide and fluoride glasses.

These promise more than an order of magnitude improvement but at longer wavelengths. The theoretical prediction with such glasses is that the loss would be ~10^{-3} dB/km at $\lambda = 3.5$ μm. This means the attenuation length will be 40,000 km. No repeaters will be required either for trans-Atlantic or trans-Pacific communication with these cables, when they become available.

The raw material for silicate glass technology (melting temperature 2000°C) is the same as that used in the semiconductor industry, and is therefore commercially available. The standard procedure is to bubble oxygen to reduce impurities in the melted silica. Addition of materials like GeO_2, Al_2O_3, P_2O_5, result in increasing the refractive index while dopants like P_2O_3, F decrease the refractive index.

Two types of optical fibres are in use today - the single mode and multimode. In single mode, the propagation of the optical beam is along the axis of the cable. In the multimode, different propagation modes are possible of a layer of GaAs sandwiched between n-type and p-type layers of $Al_xFa_{1-x}As$ which acts simultaneously as an optical waveguide and as a confinement region for the carriers injected into the GaAs layer in the forward bias condition. Thus the DH laser invented by Panish and Hayashi operates at room temperature and gives out continuous wave radiation at 8800A; extrapolated lifetimes of over millions of years became possible and therefore appeared most suitable for communication applications. However, this wavelength was not the ideal one from the point of view of fibre communication which has its lowest attenuation at longer wavelengths. This requirement led to the development of other types, in particular those made using the III-V ternary and quartenary mixed crystals with combinations of aluminium, gallium, indium, antimony and phosphorus -
$GaAs_{1-x}Sb_x$, $\lambda = 1.06$ μm
$In_{1-x}Ga_xAs_{y-1}/InP$
$In_{1-x}Ga_xAs/In_{1-y}Ga_yP$

The development of these have depended on Molecular Beam Epitaxy (MBA) and Metalorganic Vapour Phase Epitaxy (MOCVD) which allow controlled crystal growth, an atomic layer at a time. High quality defect-free materials with a thickness of only 10Å have been achieved. Quantisation of energy states and quantum tunneling effects have been demonstrated in super lattice structures of lattice matched $GaAs\text{-}Al_xGa_{1-x}$ and InGaAsP.

AlGaAs devices on GaAs and InGaAsP devices cover the wavelength region 0.8 to 1.6 µm. In GaAsP on GaAs and GaAsP devices produce lasing action at the shorter wavelength of 0.64 µm in the visible region.

Detectors

Upto a wavelength of 0.85 µm silicon detectors are quite satisfactory. However, beyond 1 µm, silicon ceases to function and either germanium or indium gallium arsenide detectors are necessary. Germanium Avalanche photo diodes have a good frequency response upto 2 GHz. Integrated PIN photo diodes have better sensitivity with silicon bipolar junction transistor than field effect transistor above data rates of 300 Mps. For data rates less than 100 Mps, PIN photo diode GaAs MESFET or Si MESFET are superior.

Bistable Switches

The bit rate performance of the advanced electronic circuits have reached 'physical', rather than 'fabrication', limitations. One approach to overcome this problem is to use hybrid systems composed of optical and electronic devices. It has also been feasible to develop all optical bistable switches.

Indium Antimony Bistable System

In narrow gap semiconductors, such as InSb, InAs, Cd Hg Te, the dynamical Burstein-Moss effect leads to large change in refractive index per unit radiance (n_2). In InSb at 80°K, $\lambda = 5.5\ \mu m$, $n_2 = cm^2/KW$. It is this nonlinearity that is exploited in the bistable devices.

The optical basic elements are formed from single crystals of InSb which are polished to form plane parallel 70-500 m thick etalons. The natural reflectivity of the two semiconductor - air interfaces (~36%) produces sufficient optical feedback to result in bistable operation with few milliwatts. Since the laser power required to induce switching is low heating is low and continuous operation becomes feasible.

The bistable switches are operated at a level below, but very close to, the switching power; as a result, with InSb devices, it has been possible to effect the switching in time scales of picoseconds.

These optical bistable elements can be used as both logic gates and memory elements. The facility to switch from one transmission level to another when biased in the bistable region, and then latch on stably in the new state, provides the memory action. For incorporation in the computer it is necessary that the output from each be sufficient to drive a minimum of two identical gates - be able to cascade (fanout potential). Fanout figures of 20-200 have been realised.

Appendix-3

Solid State lasers
Annexure from Prof Sreekantan's note on the Photon Era

The classic paper of Schawlow and Townes, spelling out the conditions for laser oscillations in the visible and infrared using optical resonant cavities for mode selection and feed back, ushered in the laser era. The first laser was the Ruby laser realised by Maiman in 1960, the wavelength being $\lambda = 0.6943\ \mu m$. A variety of lasers have been developed since then; gas lasers, metal vapour lasers, dye lasers, solid state lasers, colour centre lasers, spin flip lasers, pulsed lasers, etc. The use of lasers range from fundamental studies in physics and chemistry to applications in industry, surgery, communications, computers and defence.

From the point of view of communications, the most significant development has been the capability to produce solid state lasers that operate at room temperature and lase at wavelengths at which the optical fibres have the lowest attenuation.

The first solid state laser was made from Nd ions in $CaWO_4$ lattice - lasing at 1.06 μm, through optical pumping with a flash lamp. In 1963 laser emission was demonstrated in nickel, cobalt and vanadium ions in inulating lattices. In 1964 lasing was achieved with Nd ions in Yttrium aluminium garnet (YAG); this laser has vast industrial and defence applications.

The earliest semiconductor laser consisted of the p-n junction in Gallium Arsenide (GaAs), operated under pulsed conditions at low temperatures. In 1970 there was a major breakthrough in semiconductor lasers - the Double Heterostructure Lasers - the Aluminium Gallium Arsenide DH lasers. The hetero-junction between GaAs and $Al_xGa_{1-x}As$ system proved ideal for confining the optical radiation as well as the electrons. The near lattice match between the two materials results in defect-free interfaces.

Single mode has now largely supplanted multimode fibres for long haul applications. The cost per meter of the two types of fibres is about the same. But in single mode transmission, the switches, connectors etc. cost more. Multimode fibres require less precise control of dimensions and are easier to couple. To support a bit rate of say 280 megabits/s, if multimode is used, repeaters have to be used every 10-15 km because of dispersion. The single mode requires, on the other hand, repeaters at intervals of about 50km.

Fibres which maintain the polarisation of the light over long distances have also been developed.

A new fabrication technique known as 'Sol-gel' process has been developed. $Si(OCH_3)_4$ which is commercially available in pure form can be hydrolysed to form gels which can be cast into any shape and dried. The gel is sintered into glass before drawing into fibre. At present, with this technique, cables with 6 dB/km at $\lambda = 0.85$ μm have been fabricated.

Plastic fibres are cheap and easy to repair. The loss is ~ 20 dB/km. Therefore they are useful only for short haul applications.

Appendix 4

Extracts from a Survey of the Indian Work on Fibre Optics

Dr N B Chakrabarti

Chronologically speaking, the first Indian work on fibre optics was started at the Department of Physics, Indian Institute of Technology, Delhi, in the early 70s. This work concentrated on propagation characteristics of optical fibres. P&T, IRDE and the IITs got involved in fibre optic communications, instrumentation and efforts for fibre growth in the late 70s. A large number of industries, R&D organisations and educational institutes have started taking lively interest in fibre optic applications since 1981. Fortunately efforts are now being made to establish industries for fabrication of optical fibre and components. Substantial resources are being placed at the disposal of groups interested in fibre data transmission applications. There is therefore an air of buoyant optimism that fibre optic work in the country is coming of age. In order that such hopes do not flounder on the rocks of bad planning, it is necessary to take stock and identify strengths and weaknesses in the Indian effort in this area.

It is convenient to divide the work on fibre optics into studies on (a) fibre medium-fibre growth technology of characterisation and propagation (b)opto-electronic materials, sources and detector and (c) system studies.

Optical Fibre Growth Technology, Propagation Characteristics and Measurements

Work on fibre growth was taken up by IRDE, and the IITs at Kanpur and Kharagpur in the later 70s, but there is not a single report obtainable on their performances. The Central Glass and Ceramic Research Institute (CGCRI), Calcutta, which started work about three years ago, has been successful in making multimode and single mode fibres using MCVD technique with controllable profile. The multimode fibre has typically an attenuation of about 10 dB/km at 840 mm. Hindustan Cables, Hyderabad, have a comprehensive project for setting up manufacturing facilities for optical fibres, cables and optical line system. Similar plans have been undertaken by the P&T.

Characterisation facilities have been established in many R&D organisations and the IITs for measurement of impulse response, attenuation, dispersion, and geometric parameters. Characterisation work carried out at IIT, Delhi includes: (a) refractive index profile measurements of single mode and multimode fibres by the reflected near-field scanning techniques (b) SM fibre characterisation from far-field measurements (c) differential mode loss measurements (d) measurement of dispersion of a 300 ps laser pulse and (e) splice loss measurements.

IIT, Kharagpur, also has facilities for measurement of attenuation by cutback and OTDR between 600-100 nm, dispersion by pulse broadening and geometric parameters by transverse scattering. Work carried out at IIT, Madras includes: (a) impulse response and attenuation (b) transverse back scatter method for defining profile for graded index and step index fibres and (c) dispersion. Similar work has been reported from IIT, Kanpur, CSIO, and CEERI.

Propagation Studies Analytical work on optical waveguides at IIT, Delhi has been very extensive and widely acknowledged. These investigations cover modal analysis, pulse dispersion, attenuation and aberrations in fibres with arbitrary index profile. Considerable work has also been done on propagation in integrated optical wave-guides and directional couplers. Some work on calculation of cut-off frequencies in fibres of arbitrary index profiles and propagation characteristics of eccentric core fibres has also been reported from IIT, Kharagpur.

Opto-Electronic Materials, Sources and Detectors

Opto-electronic Materials can be classified into (a) III-IV semi-conductor materials for sources detectors, (b) acousto-optic and electro-optic materials such as lithium niobate and lithium tatntalate and (c) materials for high speed gigabit electronics.

There have been rather preliminary studies on opto-electronic materials and no work on LEDs and lasers; There has also been very little work on detectors. The laboratories engaged in development of materials relevant to fibre optic sources and detectors are SSPL (GaAs based materials), TIFR (GaAs and InP) and IIT, Kharagpur (InP). LPE growth and InP for fibre optic sources has been reported from the Materials Science Centre, IIT, Kharagpur; earlier, solute diffusion and gradient freeze methods were used for growing InP.

High-capacity wideband optical fibre systems require very fast repeaters, multiplexes, demultiplexers and decision circuits, with subnanosecond gate delays. Gigabit mux circuits may be implemented using GaAs MESFET and bipolar technology. Large BL systems are based on long wavelength single mode fibres, single-frequency lasers, fast detectors and appropriate modulation and detection techniques. Coherent communication, promising an SNR improvement of 18-20 dB, is not possible unless single-frequency lasers are available.

Detectors The development of a silicon-pin photodetector has been reported from SSPL. The detector has a response better than 5 ns, a quantum efficiency of 90 percent and a dark current less than 10nA. A photo-parametric detector using a junction or MIS varactor for sub-carrier amplification has been reported from IIT, Kharagpur and analytical studies on frequency response and noise characteristics of avalanche photodetector have been carried out.

System Studies

It appears that system studies have, by and large, been limited to short-wavelength, short-haul and a bit rate of 10 MHz and there is, consequently, no open literature. Fibre optic communication activity was initiated in Indian P&T in 1976 and a trial route on multimode fibre, carrying, an 8 Mb/s system, was implemented in 1978-79. This early work has been extended to some short-haul 35 Mb/s and 140 Mb/s system at 850 nm and work has been undertaken on 1300 nm video link using graded index fibre. P&T has now taken up a project for establishing an integrated fibre optic facility which will provide optical terminal equipment, fibres and cables, with a capacity for 40,000 fibre-kms with associated line equipment. Indian Telephone Industries (ITI) had been carrying out development work on fibre optic transmission systems since 1979, but no reports are available on the current capability. Sponsored work on short-distance digital links system had been carried out at the IITs. The work at IIT, Madras, can claim a degree of maturity. A fibre optic internal communication system for a vehicular application has been designed and satisfactorily implemented. It is heartening to note that IIT, Madras, has taken up work on development of 565 Md/s with line coding and equalization. A 5-km fibre-optic digital link using GI fibres, LED and PIN photodetector at a bit rate of 10 MHz has been developed by IIT, Kanpur. Subsystems developed include 5B/6B encoder/decoder and bit synchronisation. Work has also been carried in the important area of wavelength division multiplexing at 820 nm and 900 nm, and also equaliser, SSMA and integrated voice and data communication system. Short distance digital fibre optic links have been made at IIT Kharagpur. Studies have also been made on performances of optical receivers employing avalanche photodetectors. Considerable work has been done on timing recovery and bit synchronisers.

Shortcomings and a Plea for a National Laboratory

The above account indicates that: (a) work on optical waveguide propagation has bee substantial, (b) the activity on fibre drawing has been limited to multimode fibres in the short wavelength region, (c) system studies except for those by P&T are confined to few MHz. kms in the 0.85 micron region, but there have been recent efforts for enlarging the scope of applications, (d) very little work has been done on opto-electronics: sources, detectors and associated materials and high-speed electronics, there being no group working on semi-conductor lasers. If the Indian R&D

response to the challenge of fibre optics has been pitifully inadequate and halting, it is because of a myopic view which links support to immediate volume of local demand and diffident emphasis on appropriate technology. It is important to foresee the prevading use of fibre optics in all data transmission systems, in industrial control and instrumentation, P&T networks, computer network, for majority of long distance communication in the future. The obsession with first generation short haul short wavelength low-speed systems must therefore yield place to an endeavour to organize R&D activities to meet the challenge of 100 GHz. km high-speed systems, which need low-loss single mode fibres, single mode single frequency lasers, wideband low nose detectors and appropriate communication technique.

If we are to take advantage of the potentiality of fibre systems in extending and improving the communication facilities in our country, and to provide a useful tool to our industries, it is essential for us to first realise the immensity of the task in this highly competitive multidisciplinary field. The work done so far does not go much beyond scaled down feasibility study of pre-first generation technology and systems. Our capability in making multimode/single mode fibres of rigid optical and mechanical specifications, making LEDS and lasers of necessary power and spectral character compatible with the fibres, fabricating detectors of required sensitivity and bandwith, developing high speed circuits necessary for FOC, and also in building reliable communication nets must be generated. All these tasks must be co-ordinated and accomplished as part of an integrated plan which must take us to the third generation stage by 1988. This will be possible only if a central organisation, perhaps meodelled after ISRO, is established. The central laboratory may have the following sections:

I (a) Fibre making and characterisation, (b) Cabling, splicing, mechanical and environmental testing, (c) Connectors and couplers, (d) Optics.

II Opto-electronic materials: (a) Compound semi-conductor crystal growth, (b) Electro-optic and accoustic-optic material.

III (a) Fabrication of multimode fibre coupled LED, (b) Fabrication of long wavelength lasers coupled to single mode fibres, (c) Fabrication of dynamic single mode lasers, (d) Fabrication of short wave detectors, (e) Fabrication of longwave detectors.

IV Development of high speed devices and integrated circuits.

V System development and field trail.

It will be necessary to involve electronics and tele-communication industries and the universities and R&D organisations with the activities. The role of universities must, however, be recognised as being rather limited: universities can only help (a) to throw light on the competitiveness of specific technology options and (b) to generate the required innovation.

Appendix 5

Indian Institutions Studying Photonics

Indian Institute of Technology, Delhi (*Dr B P Pal*)
Indian Institute of Technology, Kanpur (*Drs Sanyal, Maskara. Chakrabarti*)
Indian Institute of Technology, Bombay
Indian Institute of Technology, Madras
Indian Institute of Science, Bangalore (*Dr Pappu*)
Solid State Physics Laboratory, Delhi
Instrumentation Research and Development Establishment, Dehra Dun (*Dr Hardaynath*)
Central Scientific Instruments Organisation, Chandigarh
CGCRI, Calcutta
TIFR, Bombay (*Dr Narasimhan*)
BARC, Bombay (*Dr Bhawalkar*)
CEERI, Pilani
Indian Association for the Cultivation of Science, Calcutta

Appendix 6

The Opto-electronics Joint Research Laboratory, Japan

The Opto-electronics Joint Research Laboratory was set up at Kanegawa, Japan in 1981, as a national project sponsored by MITI.

The joint research laboratory is using buildings of the Fujitsu Research

Laboratory (1500 m^2 floor space) and is staffed by 50 research engineers/ physicists representing associated industries and the electro-technical laboratory. Scientists and technologists are drawn from nine companies - Fujitsu, Furukawa, Hitachi, Matsuhita, Mitsubishi, NEC, Oki, Sumimoto and Toshiba.

The research staff are divided into six collaborating groups:

(a) Bulk crystal growth (b) Maskless ion implantation, (c) Epitaxial growth, (d) applied suface physics, (e) Fabrication technology and (f) analysis and characterisation.

Some of its important achievements by 1985 are

- Growth and characterisation of undoped GaAs single crystals by new magnetic field applied LEC (Liquid Encapsulated Czochralski) technique.
- Focussed ion implementation for opto-electronic integrated circuits.
- GaAs and AIGsAs anisotropic fine pattern etching using a new reactive ion beam etching.

The monolithic integration of optical and electrical devices called opto-electronic Integrated Circuit (OEIC) is one of the main objectives. The first application of OEIC will be in high speed optical communication.

3

Priorities of Genetic Research in India

It is now obvious that it is possible to reorder genetic material at will, and to grow unlimited copies of genes of humans and animals in bacteria.... Modern biology will, therefore, exert a considerable influence on the health and well-being of mankind in the years to come.

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3

Priorities of Genetic Research in India

Preamble

The science of genetics secured its mooring in the beginning of this century with the rediscovery of Mendelian laws of heredity. In this relatively short span of just 87 years, it has revolutionised our understanding of the intricacies of biological functions and our ability to manipulate biological systems. The latter is examplified by a number of high yielding varieties which have been developed in a number of crop plants and improved microbial strains for pharmaceutical and fermentation industries. The impact of new advancements in genetics for crop improvement, however, has been limited. This is due, to a large extent, to our inability to perform finer genetics dissection of some of the key biological processes like photosynthesis and stress tolerance. In minor cereals, oil seeds and pulses, which form the critical components of Indian agriculture, even sound conventional genetic analysis is lacking. In order to make predictable and substantial advancements in the production potentials of these crop plants, a systematic genetic analysis of key components is essential. This can be achieved by following the established conventional procedures of genetic analysis and by adopting the latest techniques of biotechnology and genetic engineering.

The microbes, because of ease with which their genetic material can be manipulated, have received far greater attention and this, in turn, has yielded rich dividends both of applied and basic interests. With the advancement in the techniques of genetic engineering it has now become possible to alter these organisms at will and make them economically more useful. Also, these organisms are serving as "factories" for commercially synthesising an array of foreign products of medicinal and industrial value. The art of tailoring the microbes in India is in its infancy. It is, therefore, essential that concerted efforts are made in understanding the basic genetic mechanisms in some of the important microbes so that superior strains for commercial exploitation can be developed indigenously. ■

1 Research in Plant Genetics

1.1 Basic Genetics and Cytogenetics

Although it is difficult to single out any one area of investigation in genetics that has made the greatest contribution to the field, investigations of linkage and recombination of genes certainly have been the most instructive and provocative. Therefore, a basic understanding of the precise location of genes in specific chromosomal locations, and the variations in their transmission, is essential for the scientific improvements of plants.

The importance of a knowledge of a basic cytogenetic phenomena, such as deletion, duplication, inversion, translocation, polyploidy and aneuploidy in plant breeding cannot be over emphasised. In India, cytogenetic research had a strong base in some of our leading institutions (e.g. IARI, New Delhi) in the 60s and excellent contributions were made in some crop species, specially in wheat and rice. However, in the 70s, emphasis in research shifted to achieving results of an applied nature, and researchers of basic genetics and cytogenetics were relegated to the background. It is vital that due importance and recognition be restored to good genetic work in crop plants so that we can taken advantage of both the conventional background and the futuristic new approaches viz., genetic engineering.

1.2 Priorities

In terms of choice of crops and areas of investigations, identifications are summarised in Table 1.

Table 1

Priorities for Conventional Research

	Objectives	Crop-species	Time (Years)	Institutions	Cost (Rs.Cr.)	Implication
1	Construction of linkage maps	*Cajanus cajan*	5-7	Genetics Division, IARI, New Delhi; Genetics Dept., Mau, Parbhani.	3	The basic understanding of the location of specific genes in precise chromosomal locations and the variation in their transmission behaviour is essential for the scientific improvement of plants for higher productiviy. Besides, cytogenetic studies may help in understanding the phylogenetic relationships of crop species.
		Cicer arietinum	5-7	Dept. of Genetics, HAU, Hisar, Dept. of Genetics PAU, Ludhiana.		
		Brassica Sapp.	5-7	Genetics Division, IARI; Dept. of Genetics, HAU; Dept. of Genetics, PAU.		
		Helianthus annus	5-7	Genetics Division, IARI.		
		Arachis hypogea	5-7	Genetics Division, IARI.		

Table 1 (*Contd.*)

Objectives	Crop-species	Time (Years)	Institutions	Cost (Rs.Cr.)	Implication
2 Genetics of traits of economic importance (including flower drop in *Cajanus* and *Cicer* and remedying by genetic manipulation; resistance to pests and diseases)	*Cajanus cajan*	10	Genetics Division, IARI; Genetics Dept., G.B. Pant Univ. of Agriculture.	3	
	Cicer arietinum	10	Dept. of Genetics, HAU; Dept. of Genetics,, PAU.		
	Brassica Sapp.	10	Genetics Division, IARI; Dept. of Genetics, HAU; Dept. of Genetics, PAU.		
	Helianthus annus	10	Div. of Genetics, UAS, Bangalore		
	Arachis hypogea	10	Genetics Division,		
3 Genetic characterisation of cytoplasmically inherited traits	*Brassica Sapp.*	5	Genetics Divisions, IARI; Dept. of Genetics, PAU; Dept. of Genetics, HAU.		

Table 1 (*Contd.*)

	Objectives	Crop-species	Time (Years)	Institutions	Cost (Rs.Cr.)	Implication
4	Identification of key components (morphological, physiological, biochemical) for genetic characterisation and selection of specific genotypes crucial for yield stability	*Cicer*, *Cajanus*, *Brassica*, *Arachis*	5-10	IARI, HAU, PAU.	1	These researches will help increase yield stability in these crops.
5	Identifying major genes contributing to source and sink development (biomass, LAI, rate of photosynthesis) and BNF (nitrogenase activities; nodule mass; nodule number and nature in	*Cajanus*, *Cicer*, *Arachis*	5-10	IARI, HAU, Bharathidasan Univ., Tiruchirapalli, ICRISAT. Hyderabad.	1.5	

Table 1 (*Contd.*)

	Objectives	Crop-species	Time (Years)	Institutions	Cost (Rs.Cr.)	Implication
	relation to soil rhizobia and/or specific rhizobial strains)					
6	Genetics of host pathogen, relationships (Genetics of virulance and identification of physiological specialisation of important disease causing organisms; genetics of host genes for resistance)	*Cajanus*, *Cicer*, *Arachis*	5-10	Genetics Div., IARI, BARC PAU, TNAU, Coimbatore	1.5	Will help in breeding of resistant geneotypes
7	Genetics of soil quantity & quality.	*Brassica*, *Sunflower*	5-10	IARI, UAS, Banaglore, HAU.	0.5	To design oilseeds with specifc fatty acid composition.

2 Biotechnology

The application of conventional plant breeding methods will continue to be the primary approach leading to the development of superior plant varieties. However, much excitement and potential have been provided by the rapid development of plant cell and tissue culture methods, R-DNA technology and molecular approaches to crop improvement.

Plant cell and tissue culture offers great potential for the future. Manipulations of genetic material using plant cell and tissue culture provide input to plant breeding efforts at two levels: (a) to make available, to breeders, materials such as genetic and cytogenetic variants, haploids, wide cross hybride, disease free stocks, and a large number of propagules: (b) possibly the most important long range contribution of plant cell and tissue culture methods is to provide the bridge between molecular genetic engineering techniques and plant breeding.

A basic problem, encountered in achieving *in vitro* culture capability with genotypes of agricultural importance, is the general lack of quantitative information on the physiology, biochemistry and developmental aspects of plant cells in culture. Another problem is the inability to regenerate complete plants from callus, single cells and protoplasts. Although it is easy to regenerate plants from protoplasts, single cells or callus tissues of a few species, mainly belonging to *Solanaceae*, by embryogenesis of organ initiation, it is much more difficult in the case of legumes, oil seeds, palms (coconut) and many other plants. The reason is our lack of understanding of the basic mechanisms whereby nutrients and hormones elicit the required responses.

Priority areas of biotechnology research relevant to Indian needs are summarised in Table 2.

3 Application of R-DNA

Application of R-DNA techniques for crop improvement requires a

Table 2

Priorities for Plant Biotechnological Research in India

Objectives	Crop-species	Time (Years)	Institutions	Cost (Rs.Cr.)	Implication
1 Development of techniques for somatic embryogenesis and micropropagation	*Cajanus cajan*	3-5	Botany Dept., Delhi University Genetics Dept., Osmania University, HLRC	3	Useful in rapid bulking up of stock material which is extremely limited; maintenance of inbred lines, essential for F1 hybrids, genetic male steriles, and multiplication of particular heterozygous genotypes.
	Cicer arietinum	3-5	Life Sci. Dept., JNU, Centre for Biotechnology, IARI.		
	Brassica Spp.	3-5	TERI, New Delhi, Genetics Dept. HAU, Centre for Biotechnology, IARI.		
	Helianthus annus	3-5	Division of Cell Biology, IISc., Bangalore.		
	Arachis hypogea	3-5	ICRISAT, Genetics Dept. Osmania University, Div. of Biotechnology, NCL, Pune		

Table 2 (*Contd.*)

	Objectives	Crop-species	Time (Years)	Institutions	Cost (Rs.Cr.)	Implication
		Cocos nucifera	5	HLRC, Div. of Biochemistry, NCL; Genetics Division, CPCRI; Genetics Division, TNAU, Coimabtore.		
		Camellia sinensia	3-5	HLRC; TRA Tocklai; UPASI, Valparai.		
2	Molecular probes for selection efficiency for disease resistance.	*Oryza sativa* *Solamum* tubersum L. esculentum etc.	3-5	Biotechnology Centre, IARI, New Delhi	0.5	
3	Induction of male sterile lines	*Cajanus, Cicer, Brassica Helianthus, etc.*	5-7	Biotechnology Centre, IARI TERI, New Delhi	0.5	

Table 2 (*Contd.*)

	Objectives	Crop-species	Time (Years)	Institutions	Cost (Rs.Cr.)	Implication
4	Embryo rescue from interspecific crosses	*Cajanus cajan*	3	Centre for Biotechnology, IARI Genetics Division, G.B. Pant, University of Agriculture and Technology.	1.5	Recovery of hybrids that combine desirable genotypes of two species.
		Cicer arietinum	3	Dept. of Genetics, HAU; Biotechnology Centre, IARI.		
		Brassica spp.		Dept. of Genetics, HAU; Centre for Biotechnology, IARI.		
		Helianthus annus	3	Div. of Cell Biology, IISc. in collaboration with UAS, Bangalore		
		Arachis hypogea	3	Genetics Div., TNAU; Botany Dept. MS Univ. in collaboration with Gujarat Agriculture University.		

Table 2 (*Contd.*)

	Objectives	Crop-species	Time (Years)	Institutions	Cost (Rs.Cr.)	Implication
5	Production of haploids through anther culture	*Brassica spp.* *Helianthus annus*	3-5	Botany Dept., Delhi University Division of Cell Biology, IISc., Bangalore	1	For Production of homozygous lines and generation of aneuploid stocks in genetic analysis.
6	Somaclonal variation for genetic variability	*Cajanus cajan*	10	Centre for Biotechnology, IARI, G.B. Pant University of Agriculture and Technology	2	Selection of variability for disease resistance, herbicide tolerance, stress tolerance and various biochemical mutants.
		Cicer arietinum	10	Department of Genetics, HAU, Hisar Biotechnology Centre, IARI.		
		Brassica spp.	7	Centre for Biotechnology, IARI, TERI, New Delhi.		
		Helianthus annus	5-7	Division of Cell Bio-logy, IISc., in collaboration with UAS, Bangalore		

Table 2 (*Contd.*)

Objectives	Crop-species	Time (Years)	Institutions	Cost (Rs.Cr.)	Implication
	Arachis	5	Genetics Division, TNAU, Coimbatore; ICRISAT, Hyderabad.		
7 Somatic cell hybridisation	*Brassica spp.*	10	TERI, New Delhi, Centre for Biotechnology, AIRI, Botany Department, Bose Institute	0.5	For production of cytoplasmic hybrids without extensive back crossing (transfer of cms); synthesis of *B. napus* and *B. carinata.*

procedure for introducing DNA into host cells followed by its integration and expression. Agrobacteria which are the carriers of Ti and Ri plasmids are excellent natural systems for transfer of genetic information mainly into dicotyledonous plants. Recent work has shown, however, that Ti plasmids can also be used to transform monocots like corn, wheat and rice.

3.1 Pre-requisites for Application of R-DNA Research in Plants

- Repression of undesirable genes using antisense RNA technology
- Subcellular targeting of gene products using transit peptides
- Monitoring the specificity of targeted genes by a non-invasive assay, such as by use of the luciferase gene as reporter
- Isolation and testing of new tissue specific promoters
- Development of physical techniques of gene transfer (micro-injection, electroporation/electrofusion)
- Establishment of plant cell cultures on a large scale
- Isolation and characterisation of single genes of economic importance (such as genes for disease resistance and salt/drought resistance, etc.)

The areas of research in genetics for enhancing plant productivity are:

- Identification of microbial genes which, when transferred to plants, may confer resistance to herbicides, diseases and other stresses.
- Development of transgenic plants that produce their own insecticides (e.g. cloning BT d-endotoxin gene in crops susceptible to larvae of lepidoptera).

3.2 Research on Rhizobia

Crops fixing nitrogen, by means of endosymbiotic rhizobia, are a major world source of protein and soil nitrogen. The interactions between the rhizobia and host plant are currently being unravelled (*Fig. 1*). This may lead to more efficient nitrogen fixation and new (like cereals) nodulated, nitrogen fixing crops.

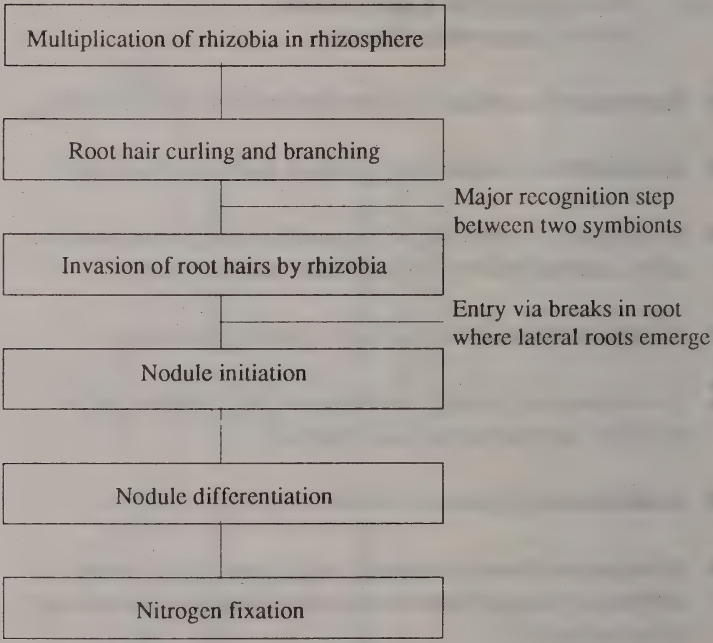
Multiplication of rhizobia in rhizosphere
Root hair curling and branching
Major recognition step between two symbionts
Invasion of root hairs by rhizobia
Entry via breaks in root where lateral roots emerge
Nodule initiation
Nodule differentiation
Nitrogen fixation

Fig. 1 Sequence of steps leading to the formation of a legume nodule.

An efficient *Rhizobium* strain should meet the following criteria:

- Survive and multiply in soil-they therefore need to be good saprophytes.
- Compete successfully with indigenous rhizobia for infection sites on the plant, and

- Once in plant, match their metabolism with that of the host so that the two together produce the maximum amount of organic nitrogen with the minimum expenditure of energy.

Genetic engineering of Rhizobia will involve:

- H_2 recycling (*hup* genes)

- Mutants resistant to high temperature, drought, high and low P^H of soil and anti-bacterial compounds present on seed coat surfaces of many legumes (environmentally adapted strains)

- Host range extension of Rhizobia by transfer of *nif* genes to monocots through *Agrobacteria*

- Study of *Sesbania rostrata* (identified by French scientists in Senegal) which forms nodules on both stems and roots.

4 Research in Microbial Genetics

4.1 Classical Genetical Research in Yeasts (for increasing alcohol productivity)

Although the life cycle of *Saccharomyces cerevisiae* alternates between haploid and diploid states, the polyploids are commonly found and preferred industrially due to their stability. Yeasts constitute one of the most important group of organisms employed in commercial biotechnology. An array of techniques are now available to researchers to manipulate the yeast genome to advantage (mutation - selection, hybridisation, rare mating, spheroplast fusion, DNA transformation and gene cloning). Some of these techniques are independent of ploidy and mating type. A judicious combination of these techniques can tailor yeast strains to suit a given process, substrate and profile of flavour/aroma, etc.

Briefly, the areas of genetic improvement are:

- Thermophilic strains for semiaseptic fermentations and incorporation of killer activity towards organisms (for protected fermentation)

- Incorporation of catabolic properties to allow use of ligno-cellulosics, starch, etc. as alternative raw materials (for biomass recycling and energy recovery).
- Incorporation of flocculation or flotation gene(s) to improve harvest/cell recycle properties.
- Resistance to feed back inhibition; improvements in ethanol productivity, tolerance and titer.
- Elimination of unwanted products of catabolism, that is, direction of catabolism towards ethanol.

One of the most promising organisms for alcohol production is *Zymomonas mobilis*. Strains for *Z. mobilis* have been shown to produce ethanol from highly concentrated sugar and fructose media. In a continuous cell recycle system, a volumetric ethanol productivity of 120 g/l/h has been reached. The wide range of genetic engineering techniques now available can be immediately applied to the important problem of broadening the range of substrates utilised by *Zymomonas* and improving its ethanol tolerance.

4.2 Engineering Tomorrow's Antibiotics

Pencillin's toxicity towards bacteria was first noticed by Alexander Fleming in the 1920s, and the selectivity of the effect was demonstrated by Howard Florey. Repeated mutations (by X-rays, UV radiation and nitrogen mustard) were necessary to create a strain of the mold *Penicillium chrysogenum* that synthesised enough penicillin to form the basis of commercial process. Appropriate strains of organisms today, under carefully controlled fermentation, produce 20-70 g/l of penicillin against an initial yield of less than 100m g/l.

Improvement of production capability of antibiotic producing strains will require:

- The introduction of enzymes used in modification of antibiotics in producer strains. For example, introduction of pencillin acylase in *Penicillium chrysogenum* will directly produce 6-amino pencillanic acid.

- Protoplast fusions to produce new hybrid cells which may give rise to novel antibiotics with special beneficial effects, and free from toxic side effects.

4.3 Vaccines of the Future and DNA Probes

In currently available vaccines (attenuated or killed), there is a constant problem of ensuring that the product is innocuous. Subunit vaccines which contain one of a few major antigens for the infectious agent, but none of its genetic potential, eliminate many problems associated with the use of whole organisms as vaccines. The following steps are used in the process:

- Identification and characterisation of antigens which are sufficiently immunogenic

- Cloning and expression of these antigens (in bacterial or vaccinia vectors) for large scale production in microbial hosts.

- Amino acid substitution of antigen (by site specific mutagenesis) may allow it to be used against a number of viral serotypes (e.g. in case of influenza).

- Formulation (suitable for testing) of candidate vaccine.

Such vaccines might:

- Be safe due to lack of virus as a whole, or its undesirable mutants.
- Have an indefinite shelf life due to thermal stability.
- Be cheaper.

The genes for hepatitis B surface antigen have been cloned and expressed. The product for use of vaccine (first genetically engineered vaccine approved for human use) has a precise amino acid composition and structure. It is under clinical trials and will soon be ready for application. Similarly, the protective coat proteins of the 'Foot and Mouth' disease virus have been cloned and expressed. This vaccine is also on trial; available data prove its efficiency. The following table (Table 3) presents some examples of diseases for which current vaccine status is low, and gene cloning technology can be applied for vaccine development. The vaccinia virus system can be used to produce combination vaccines to protect from various infections by a single injection. However, it should be confirmed that a combination vaccine will indeed protect as well as the vaccines injected separately.

Table 3

Current Vaccine Status for Some Diseases

	Disease	Health Significance	Current vaccine status	Feasibility of using gene cloning in vaccine development
Human	Tuberculosis	High	Questionable	Medium
	Leprosy	High	Low	Medium
	Encephalitis	High	Poor	Good
	Rabies	High	Variable	Good
	Malaria	High	None	Medium
	Cholera	High	Questionable	Good
	Gonorrhea	High	None needed	Basic research
	Meningitis	High	Good needed	Basic research
	Herpes	Medium	None	Medium
	Filariasis	High	None needed	Basic research
	Leishmaniasis	Medium	None needed	Basic research
Animal	FMD	High	Medium	High
	Blue Tongue	Low	None	High
	Neonatal diarrhea	High	Poor	High

In case of disease causing enterobacteria (gastroentritis, colibacillosis) an alternative to subunit vaccines exists. Defined (from the knowledge of genetic map) lethal deletion mutants of these bacteria can be developed to serve as immunogens. Such mutants do not require inactivation but they are still innocuous because they cannot replicate.

The efforts to develop subunit vaccines or deletion mutants of pathogenic bacteria must be targeted to high priority diseases as identified in the report of the expert group on 'Strategies for Quality Control of Immunobiological for Diagnosis. Therapy and prophylaxis' (SACC Report, May 1986). The technology mission in vaccination and immunisation plans to cover all subjects at risk for polio, measles, tuberculosis, diptheria, tetanus and typhoid by 1990.

The use of nucleic acid sequences as probes in hybridisation assays, for the detection of specific micro-organisms such as *Salmonella*, has tremendous versatility in many systems. Virtually any organism of interest can be detected in complex samples: viruses, bacteria, protozoans and so on, in foods, water, body tissues and fluids, etc. The most fundamental requirements for a DNA hybridisation assay are an appropriate DNA sequence to use as a probe, a method of labelling the probe molecule, and a method for detecting the label. For example, if one wishes to detect the presence of toxigenic *E. coli*, a good choice will be to clone the toxin gene from that organism and use that as a probex. Research priority in this area is to identify unique probe sequences including cryptic plasmids for various infectious agents such as *Yersinia, Campylobacter, Listeria and Legionella, etc.*

4.4 Enhancing Production of Metabolites

The objective of this exercise is cost reduction through a high yield production process using R-DNA, modified bioreactors, etc.

The objective can be met by:

- Cloning of appropriate gene(s) or trimmed gene(s) with strong promoters on multicopy plasmids. Amplification of rate limiting steps in a desired pathway by developing appropriate shunts or blocks.

- Removing attenuator control regions for overproduction of amino acids.
- Higher uptake of required compounds - use of permease (s) or permease(s) overproducing mutants.
- Temperature controlled amplification of genes using dual origin vectors.

Table 4 lists some of the microbial metabolities of industrial importance.

Table 4

Some Microbial Metabolites (Primary and Secondary) of Industrial Importance

Category	Illustrative examples
Amino acids	Glutamate, aspartate, lysine, tryptophan.
Vitamins	B_2, B_{12} C, β-Carotene.
Enzymes	Detergent proteases, starch conversion enzymes, rennin, lipases, papain substitutes (acid proteases).
Biopolymers	Zanthan, dextran, pullulan, poly β-hydroxy butyrate.
Antibiotics	Penicillins, cephalosporins, tetracyclines, peptide antibiotics.
Organic acids	Citric, lactic, gluconic, itaconic.
Alcohols/solvents/ fuels	Ethanol, isopropanol, polyols like glycerol, acetone/butanol, butanediol, biogas.
Sweeteners	Erythritol, high fructose syrup.
Nucleotides	Guanylic inosinic and xanthylic acids.
Others	Single cell protein and oil, microbial surfactants sterioids, baker's yeast, flavourants (like lactones) glibberllins.

4.5 Extending the Range of Producer Organisms: Synthesis of Eukaryotic Proteins in Prokaryotes

The remarkable progress of R-DNA technology is examplified by the production of mammalian proteins (protein drugs) in microbial and cultured mammalian cells. This power carries with it a greatly enhanced freedom of choice in selecting the host organism. Relevant advantages and disadvantages of a number of host microbial species are listed below (Table 5):

Table 5

Advantages of Host - Microbial Interactions

Organism*	Advantages	Disadvantages
E. coli	Genetics known, grows rapidly	Endotoxins, occasional human pathogens, no glycosylation
B. subtilis	Grows rapidly, used on industrial scale, secretes proteins, no endotoxins, non-pathogenic	Secretes proteases, genetics little studied
Yeast	Non-pathogenic, generally used as human food, flocculating strains, glycosylates, genetics well studied, grown on very large scale	Glycosylation different from the mammalian system
Thermophiles	Fewer contamination problems, often more stable proteins	Genetics little studied,, glycosylation not studied, pathogenicity not known

*Eukaryotic production systems (cell lines) not included here.

In spite of these developments, very little genetic information is available in some of the producer organisms like *Streptomycetes, Anaerobes and Coryyneform bacteria* which are most commonly used in industrial fermentation. Research should be conducted in the following areas in these strains:

- Genetic maps - identification and location of genes on chromosome(s).
- Develop suitable vectors for all producer organisms.
- Determine number of genes involved in a pathway to produce a given product.
- Improvement of metabolic pathways for better yield of products.

Regarding the last point, it should be noted that Genentech scientists recently modified a strain of *Erwinia herbicola* by inserting a gene from *Corynebacterium.* The recombinant ferments D-glucose, in one step instead of the four needed by the older process (Reichstein-Grussner), to immediate precursor of ascorbic acid (2-keto L-gluconate).

4.6 Protein Engineering to Alter Enzymes Produced by Micro-Organisms

Protein engineering is a powerful new tool to alter enzymes in order to select a suitable variant. The following properties of enzymes are affected:

- Thermostability
- p^H optima and profile of reaction kinetics
- Rate of catalysis
- Substrate specificity and binding affinity

In theory, any useful enzyme can be altered to serve better. Some examples of positive effects of protein engineering (by site specific mutagenesis) on enzyme activities are given in Table 6.

The enzyme can be altered at any site including the active site. Molecular modelling (computer-aided simulation) can be used to study protein dynamics which helps in identifying part of a protein

Table 6

Examples of Positive Effects of Protein Engineering

Enzyme	Modification	New property	Reference
Substilisin	met^{222}-ala	Greater bleach stability	European Patent 0130756 (1985)
T4 lysozyme	ile^{3}-cys	Increased thermostability	*Science* 226, 555 (1984)

that can be changed slightly to produce 'muteins'. The major goal of making muteins is to tailor-make an enzyme for a process or to change subtly the spectrum of effect of a protein drug (*see Fig 2*).

The research requirements in this area are:

- Development of improved producer strains by genetic engineering or cell fusion technology (for conventional fermentation processes or for production of plant/mammalian proteins by microbes).
- Minimisation of feedback and transport inhibition. Removal of transport barriers for better product separation (cell as a semipermeable reactor).
- Identification of economically important genes of bacteria that could be transferred to eukaryotes like plants and animals (recently bacterial and viral genes have been cloned and expressed in plants to confer properties of tolerance to herbicide glyphosate, larvae of lepidopteran insects and tobacco mosaic virus).
- Elucidation of mechanisms of gene regulation; gene fusions.
- Secretion/expression/high copy number vectors.
- Development of technology to selectivity turn off undesirable genes (by cloning antisense DNA construct for any given gene).

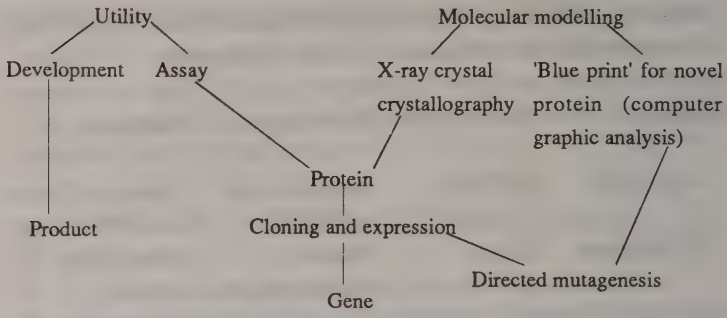

Fig. 2 Protein engineering.

- Development of technologies for transposon mutagenesis protein analysis (mini-and maxicells). Promoter probes, etc., for all producer organisms. These technologies are not yet available for coryneform bacteria which are important pathogens(*C. diphtheriae*) and also important amino acid producers (*C.glutamicum*).

- Development of shuttle mutagenesis methods in case of eukaryotes where proper transposons are not available. In essence, transpon mutagenesis is done in eukaryotic genes cloned in *E. coli*.

A summary of recommendations for research in microbial systems is given in Table 7.

5 Summary of Recommendations

5.1 Plant Genetics

Scientific improvement of crops is dependent on information on basic genetics and cytogenetics. The precise location of genes of agronomic importance should be known and the transmission of chromosomes that harbour these genes should be understood. In the 1960s, good basic work on cytogenetics in wheat and rice was done at IARI but, later in the 70s, the emphasis shifted on applied aspects. We do not even have conventional genetic analysis of critical components of Indian agriculture *viz.* minor cereals and oil seeds.

Table 7

Priority Areas of Research in Microbial Genetics

Objective	Nature of work/ Projects	Experimental strategies	Time (Years)	Cost (Rs.Cr.)	Suggested Institutions	Implications
Industrial Microbiology						
Increasing the productivity of fermentation processes	Antibiotics including new and hybrid molecules alcohol, organic and amino acids, polysaccharides, etc.	Strain improvement R-DNA, protoplast fusion, induction of thermophily and tolerance to end products, suitable tailoring of pathways.	5-10	2-4	NCL, HAL IMT, HLRC	Productivity on par with most optimised operation
Immuno and DNA dot blot assays						
Precise and rapid screening of infections	Diagnostic kits for tuberculosis, hepatitis, leprosy, etc.	Monoclonal antibodies against specific antigens; Hybridisations with probes containing specific DNA	3-5	1-1.5	NII, NIV, IISc	Precise diagnosis for effective therapy

Table 7 (*Contd.*)

Objective	Nature of work/ Projects	Experimental strategies	Time (Years)	Cost (Rs.Cr.)	Suggested Institutions	Implications
Recombinant approaches to vaccines						
Second generation vaccines (subunit/ peptide vaccines)	Vaccine for tuberculosis, amoebiasis, encephalitis, malaria, rabies, hepatitis, leshmaniasis, immune deficiency diseases and cancer, foot & mouth disease Marek's disease, rinderpest, blue tongue, etc.	Identification of immunogenices epitopes, cloning of corresponding DNA sequences and testing of candidate vaccines	5-10	3.5-7	IISc, CCMB, NIV, NII, IVRI, NDRI	Safe, cheaper, thermostable vaccines, with long shelf life
Enzyme Technology						
Tailoring the enzymes to suit industrial processes	Starch conversion enzymes cellulases, amylases, lipases, etc.	Protein engineering based on allied techniques of crystallography molecular modelling, etc.	5-10	3.5-7	IISc, CCMB, TIFR/BARC NCL/Pune University HLRC, CFTRI, HAL.	Improved catalysis at wide pH/temperature range in a host of industry processes; Production of alcohol and other chemical from cellulose

Table 7 (*Contd.*)

Objective	Nature of work/ Projects	Experimental strategies	Time (Years)	Cost (Rs.Cr.)	Suggested Institutions	Implications
Genetic Engineering						
Basic research and refinement of techniques	Development appropriate hostvector systems; identify stronge promoters and gene amplification strategies; cloning for high value pharmaceuticals (TPA blood clotting factors), Study of metabolic pathways and construction of genetic maps.	Construct and maintain a library of vectors, promoters, enhancers, etc; mutation-selection and amplification of desirable genes by antisense RNA technology and insertional inactivations.	3-10	2-6	BARC, IISc JNU, CCMB CDRI, HLRC IICB	Will provide strong support to applied research.

* As far as possible, an industrial partner/sponsor should be identified for each project and should be involved from initial stages of work.

The recommendations for a research programme are as follows:

5.1a Basic Genetic and Cytogenetics

Basic work on linkage maps, cytogenetic phenomena such as deletion, duplication, inversion, translocation, polyploidy, etc. must be pursued in pulses (arhar, gram) and oil seeds (sunflower, mustard, groundnut).

5.1b Plant Biotechnology

- Develop techniques for micropropagation and somatic embryogenesis of arhar, gram, mustard, sunflower, groundnut, tea and coconut.
- Production of haploids by anther culture to accelerate breeding.
- Embryo rescue for wide hybridisation, and to accelerate breeding.
- Somaclonal variation to develop new germplasm for breeding.
- Protoplast fusion technology to transfer cytoplasmic male sterility for new hybrids.

5.1c Recombinant DNA
(aimed mainly at capability development)

- Identify microbial genes that can be used to advantage in plants (e.g. d-endotoxin gene of *Bascillus thuringiensis*)
- Develop techniques to transfer genes in mitochondria and chloroplast, and develop assay methods that will not require sacrificing the plant.
- Improve rhizobia by improving nif,hup, nod and other gene functions.
- Develop methods leading to direct functioning of transferred genes selectively in various parts of plants, e.g., leaves, root, shoot or flowers etc., and methods to neutralise the activity of undesirable genes.
- Develop techniques for large scale of plant cells in media.

5.2 Microbial Genetics

5.2a Classical Genetical Research

- Map genes involved in production of antibiotics, organic acids etc.
- Intraspecies hybridisation in *Streptomyces* to produce new antibiotics.
- Develop strains to produce alcohol from cellulose and starch. Develop *Saccharomyces* strains that are tolerant to temperature and high alcohol concentration.
- Isolate mutants that overproduce various metabolites e.g.amino acids (lysine, methionine, glutamic acid).

5.2b Recombinant DNA Research

- Protein engineering to produce robust industrial enzymes (function at broad p^H and temperature range), e.g., proteases, lipases, amylases.
- Most of the methods to produce foreign proteins have been developed in *Bacilli, E. coli* and yeast (e.g. insulin, interferon, growth hormone etc.). The range of producer organisms should be extended to include *Streptomyces spp. and corynebacterium spp.*
- Develop new vaccines (against tuberculosis, amoebiasis, encephalitis, malaria, rabies, hepatitis, leshmaniasis, foot and mouth disease, rinderpest etc.) to control tropical infections. Suitable antigenic determinants of viral coat and the bacterial toxins should be identified. These antigens can then be produced in microbial hosts for safer, cheaper and thermostable vaccines.
- Develop immuno and DNA diagnostics (for tuberculosis, hepatitis, leprosy etc.) for precise and rapid screening.

5.3 Government Role in Promoting Research

In addition to funding relevant research (the total cost over 5-10 years is likely to be of the order of Rs 30-43 crores), the Government must pay serious attention to the following specific points:

- Collection of microbial cultures, systematic storage, maintenance and dispersal on demand. In this regard, three national culture collections (NCL, Pune; IARI, New Delhi and DRL, Kanpur) should be strengthened instead of setting up a separate centre.

- Streamlining prompt acquisition and delivery of perishable biologicals such as restriction enzymes* and the equipment used in genetic research such as DNA and peptide synthesisers and sequentors. At present, it is necessary to obtain two certificates from the Government for duty free import of these research inputs: one certificate indicating that the item/chemical is not manufactured in India, and so it can be imported; the other certificate is for exemption of duty. It is recommended that the head of a recognised research/teaching institution should be authorised to issue these certificates to reduce the red tape and bureaucratic delay.

- Maintaining gene libraries, cell lines, etc., along with culture collections.

- Maintaining a computerised data bank of genes which have been cloned and sequenced (both at DNA and protein level).

- Establishment of safety guidelines, biohazard containment procedure, etc.

- Training of scientists, technicians through short courses; long term research manpower development at the graduate level.

- Regular workshops on priorities and implementation strategies.

- International research collaboration and technology transfer.

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*The efforts of the Biochemicals Unit, created at the V.P. Chest Institute, Delhi, with the express objective of streamlining acquisition of perishable biologicals are commendable, but have not been adequate. The Government Customs Department at airports continues to show a blind adherence to unserviceable rules.

- Supporting strong linkages between 'the three solitudes': government, industry and university. Speedy transfer of insights and techniques from universities and public sector laboratories to application oriented laboratories.

- Patent laws and policing of patents.

- A special cell to directly monitor the problems and complaints of specialists with the purpose of removing the various impediments to science administration.

4

Lasers

It seems clear that the future holds even more uses for the laser - the light of the 21st century.

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Properties of Lasers

4

Lasers

Preamble

The invention of the laser in 1960 will certainly rank amongst the important inventions of this century. The unique properties of the laser make it a tool of unprecedented precision and power which has found wide applications in all areas of human endeavour. The availability of such a unique source of light has opened up new frontiers in science and technology, such as nonlinear optics, holography, optical communication, optical computers etc. Replacing conventional techniques with laser-based techniques has resulted in spectacular improvements. Thus the laser has been used to probe the structure of atoms with a precision thousands of times better than that obtained with conventional techniques. The laser can detect pollutants and impurities with high sensitivity - even the presence of a single impurity atom. The laser has been used to slow down and cool atoms to near absolute zero temperature. The laser can separate two isotopes of an element and can synthesise new compounds. In surgery, the laser, replacing the scalpel, can perform bloodless surgery with great precision. When used for drilling, cutting or welding of materials, the precision and high speed offered by the laser results in considerable reduction in processing costs. This is even more so when drilling or cutting of a hard substance like diamond is involved. ■

1 Application of Lasers

Because of its unique properties, the laser is finding wide applications in various areas. It is not possible to mention all of these applications. Hence only a few will be described briefly to illustrate the advantage of using lasers.

1.1 Laser Applications in Basic Sciences

The availability of intense, tunable and narrow linewidth radiation from lasers has revolutionised spectroscopy. In a conventional absorption spectroscopy set-up, replacing a conventional source with a tunable laser can give orders-of- magnitude improvement in the resolution. This is of advantage particularly for infra-red absorption spectroscopy.

In the measurement of the absorption spectrum, lasers are particularly advantageous when detecting weak absorption lines. Several new techniques have been developed for recording weak absorption spectra. These include optoacoustic spectroscopy, optogalvanic spectroscopy, multiphoton ionisation spectroscopy, intracavity absorption spectroscopy etc. These techniques are useful not only for study of absorption spectra but also for more practical applications such as detection of very low levels of impurities, detection and monitoring of pollution etc. It is relatively simple to measure impurity concentrations of a few parts per billion using optoacoustic spectroscopy. However, photonisation spectroscopy, the most sensitive of all these techniques, permits detection of a single impurity atom in the volume irradiated with the laser.

The lasers used for these experiments are generally tunable dye lasers which are pumped by argon ion laser, nitrogen laser, excimer laser or copper vapour laser. The argon laser pumped dye laser can give very a narrow linewidth, typically about 1 MHz. Dye lasers usually emit in the visible region of the spectrum. This can be extended to, the ultraviolet (UV) by harmonic generation in nonlinear crystals. For the infra-red region, tunable semiconductor lasers are used.

The resolution that one can get in the visible and the UV region is not limited by the linewidth of the laser. The spectral lines are broadened by various mechanisms; for example, by the Doppler effect, which limits the resolution. In a gas the typical natural linewidth of a spectral line is about 1 MHz. This line can get Doppler broadened to nearly 1000 MHz. Thus Doppler broadening will smear out any spectral features within 1000 MHz of the absorption line. Several nonlinear spectroscopic techniques have also been developed to eliminate the effect of Doppler broadening. These include Lamb dip spectroscopy and the two-photon absorption spectroscopy.

Another important area of spectroscopy where the laser has almost completely replaced conventional sources is Raman spectroscopy. The high intensity of the laser has reduced the time required to record a Raman spectrum from hours to minutes. Additionally, it permits taking Raman spectra which were not possible earlier e.g. the Raman spectrum of a highly absorbing sample. Surface enhanced Raman spectroscopy is a powerful technique for surface analysis. The laser most widely used for Raman spectroscopy is the argon ion laser. More recently, the tunable dye laser, pumped by argon ion laser, is being used to take advantage of the enhanced scattering cross-sections in resonance Raman scattering.

Lasers have found increasing use in chemistry both as a diagnostic tool and as a mean for inducing chemical reactions. As a diagnostic tool, tunability and short pulse generation capability of the laser are important. With such lasers it is possible to study chemical reaction kinetics on picosecond times scales. Tunable lasers, when tuned to the specific resonance of a molecule, can induce bond selective chemical reactions. This process is of great importance since it can be adapted to achieve the separation of the isotopes of an element.

Laser induced fluorescence is being widely used to analyse the product state in a chemical reaction. By using pulsed lasers, both to initiate the reaction and to probe the products, it is possible to study the dynamics of the reaction. Laser excitation of molecules has also been used to study the dependence of reaction cross section on molecular orientation, molecular excitation state etc., A sophisticated apparatus, with crossed molecular beam and laser beam, has been built for such studies at many laboratories.

In a normal chemical reaction, one or more molecules, which are in thermal equilibrium, react to produce the reaction products. The molecules generally have several vibrational modes corresponding to different bonds between atoms within the molecules. In thermal equilibrium all of these modes are excited. When these molecules undergo chemical reaction it is generally the weakest bonds which break and the fragments form new molecules. However, by using a laser tuned to the vibration frequency of a specific bond, it is possible to selectively excite and break that bond thereby producing reactions products different from those produced in the usual chemical reaction. This may result in reduction in the production cost of chemicals and increase in the yield. Another application of laser chemistry is in ultra purification of chemicals. Using the principle described above, it is possible to make only impurities undergo chemical reactions resulting in products which can be easily separated. This technique will be advantageous while removing impurities which have chemical properties similar to those of the desired compound.

The lasers used in most chemical applications are dye lasers, excimer lasers, CO_2lasers and Nd:YAG lasers.

1.2 Laser Applications in Medicine

Opthalmology was perhaps the first area where the laser was put to use with advantage. Today lasers are finding wide use in almost all areas of medicine, including surgery, diagnosis etc.

The high intensity available at the focus of a laser beam is adequate to cut tissue. This has permitted the laser to be used as a surgical tool which can replace the scalpel with several advantages. First, since the laser cuts the tissue essentially by heating, the laser cauterises the blood vessels, as it cuts the tissue, thereby preventing bleeding. In organs, such as the liver, which have a large number of blood vessels, surgery using any technique other than lasers is not possible. Secondly, since the laser beam cuts the tissue without any physical object coming in contact with the tissue, the possibility of infection is less. Thirdly, the laser removes the tissue without affecting nearby cells.

In a cut made with laser, there is less trauma for the patient compared to a cut made with a knife. Thus in laser surgery there is less swelling of surrounding tissue, less pain and faster recovery.

The laser offers another major advantage in several surgical procedures: the laser beam can be guided through optical fibres, which are only about 100 microns in diameter, to internal organs of the body. The optical fibres can be inserted in the body either through natural openings or through small incisions to reach the affected organ where the laser beam can perform the required surgical operation. Using this technique several major surgical procedures such as heart by-pass surgery have been reduced almost to an outpatient treatment procedure.

Retina detachment is a serious condition which, if untreated, can lead to blindness. Lasers are routinely used to 'wed' the detached retina to the choroid. Other serious conditions of the eye which are treated effectively with lasers are diabetic retinopathy, macular degeneration, and vitrous haemorrhage. In most of these cases, an argon or krypton ion laser of about 1 watt power is used. There is some indication that by using a tunable dye laser it is possible to operate on tissue underlying another layer of tissue which is transparent to the laser radiation. Thus it may be possible to operate on blood vessels behind the retina without damaging the retina.

Glaucoma is another serious condition of the eye in which the pressure inside the eyeball increases, resulting in damage to the retina and ultimately to blindness. Nd:YAG lasers are now used to drill a small hole in the eyeball to relieve the pressure and save the sight.

Pulsed lasers can remove tissue very precisely. It is, therefore, possible to reshape the lens of the eye to correct, for example, for myopia. The procedure - radial keretotomy - is carried out with a pulsed excimer laser.

There are several other conditions of the eye which are successfully treated with the laser but only a few have been mentioned here.

The precision of laser surgery has been a major advantage for delicate operations such as in neurosurgery. Using a pulsed laser it is possible to destroy and evaporate tissue in thin layers. Thus brain tumours can be removed without affecting underlying healthy tissue.

The possibility of guiding laser beams, through hair thin glass fibres, to internal organs has been used with advantage for treating conditions which normally require a major operation. For example, bleeding ulcers normally require immediate major surgery. However, using a fibre optic endoscope with a laser, it is possible to cauterise the bleeding ulcer without making any opening in the body. Another example is in the treatment of blockage of arteries supplying blood to the heart, a condition resulting in myocardial infarction. The remedy so far was to shunt the blocked artery with one taken from another part of the body, a procedure known as by-pass surgery. The laser angioplasty technique is now available instead: here an optical fibre is inserted in an artery in the thigh or arm and pushed up to the blockage in the artery. Laser pulses sent through the optical fibre then remove the blockage.

Photoradiation therapy is a promising technique for cancer treatment. Certain dyes, namely Hemato-porphyrin derivatives (Hpd) have the property of attaching selectively to cancerous cells. When irradiated with intense red laser light from a gold vapour laser, the Hpd molecules decompose releasing singlet oxygen which kills the cancerous cell.

Lasers are being used in almost all areas of medicine but only a few of these are mentioned here.

1.3 Laser Applications in Industry

Lasers have made their mark in industrial applications also. Today lasers are routinely used for alignment and surveying, for material processing operations like welding, drilling, cutting, glazing, alloying, cladding, for non-destructive testing etc.

Since the laser beam travels in a straight line, it is used as a reference for aligning large structures such as bridges, large buildings, tunnels, pipes, mines etc. Modulated beam interferometry is used in surveying for measuring distances upto 10 km with an accuracy of a few centimetres. A two wavelength laser version of Michelson's Interferometer measures distances of up to a few tens of metres to an accuracy better than one micron, and is used to calibrate precision tools and mechanisms.

Laser drilling permits drilling holes with high aspect ratio i.e.depth to hole diameter ratio, and in hard materials such as diamond, tungsten etc. Lasers have completely replaced conventional drilling techniques to drill holes in diamonds, for making wire drawing dies, and in sapphire, for making watch bearings. Lasers are also widely used to drill fine holes in gem quality diamonds to remove black inclusions in the diamond. The hole drilled for this purpose is so small that it is not seen without a microscope, and hence does not affect the value of the gem, but the removal of the black spot significantly enhances its gem value. But perhaps the most widespread use of laser drilling is for drilling fine holes in turbine blades of jet engines to improve the performance of the engine. The number of laser drilling machines in use for this application is the highest.

Laser cutting offers the advantages of being able to cut hard materials, and "difficult-to-cut" materials such as ceramics, to a very narrow and smooth cut so that further finishing of the cut edge is not required. Lasers can also cut a small heat affected zone. Lasers are used widely for cutting metals, ceramics, plastics, cardboard, cloth etc.

Another important application of lasers in material processing is in modifying the surface properties of materials; to give better corrosion resistance, for example. The processes used are laser cladding, laser alloying and laser glazing. For laser cladding and alloying, a thin layer of appropriate metal is deposited on the finished component. The surface of the component is then scanned with a powerful laser. The coating and underlying thin layer of material melts, which, on solidification, forms a strong bond between the base metal and the clad metal. By adjusting the process parameters it is possible to mix a thin layer of the base metal and the overlying coated film to get a thin film of alloy on the surface. The clad film or the alloyed film gives a surface with the required properties while leaving the bulk unaffected.

Lasers are being used for conventional heat treatment of surfaces; for example, for heat treating crank shafts of piston engines. But laser treatment of surfaces offers other exciting possibilities. In laser heat treatment of the surface, it is possible to get very rapid cooling rates. At such cooling rates, the molten surface layer can resolidify, in the glassy phase (metglass) or in other metastable phases. These layers can have unusual properties.

In the semiconductor industry also lasers are now finding many applications. Laser annealing of solar cells improves their performance significantly. Silane can be photodecomposed to get amorphous films of silicon for solar cells. Lasers can also be used to directly 'write', on silicon wafers, the patterns required to make ICs, thus eliminating the expensive masks required in conventional methods. Laser writing of patterns is economical when special custom designed ICs, which are required in limited numbers, have to be manufactured.

There are several other applications of lasers in industry and related fields which, though important, can only be mentioned briefly here. Lasers are used for marking on metal products, plastics etc. Laser scanners are used to read bar codes on consumer goods in shops, to inspect precision components in workshops, to identify goods wagons in a moving train and to read text and other documents. Laser printers are perhaps the fastest printers available today. Lasers are used to make ultrafine powder of various chemicals which are used, for example, in powder metallurgy. Holographic interferometry is routinely used as a non-destructive technique for quality control.

1.4 Laser Applications in Communication, Processing and Storage of Data

With the invention of the laser, it was natural to try to extend the communication channels from microwaves to the optical region. The higher frequency of lasers meant higher channel capacity and the small wavelength meant smaller sizes of transmitter and receiver optics. However, the main drawback of the early line of sight communication links was their susceptibility to weather conditions. The alternative, namely communication through optical fibres, did not seem possible because of high loses in optical fibres. The breakthorugh came in 1974 when Corning produced low loss optical fibre from high purity materials. Since then there have been remarkable developments both in the optical fibre and in semiconductor laser technologies. The loss of optical fibres has been reduced to less than 0.3 dB/km at 1.5 micron wavelength (i.e., a 10 km long fibre will transmit 50% of incident light), and an even lower loss is predicted at longer wavelengths from new optical fibres under development.

Graded index fibres, in which the refractive index varies across the diameter of the fibre in a specific way, have reduced modal dispersion, thereby increasing the bandwidth of optical fibre communication links. Narrow linewidth single mode semiconductor lasers have also led to reduction in dispersion due to the material of bandwidth. Thus, it is possible to design and demonstrate an optical fibre communication link with more than a gigabit/second data rate. Similarly, the repeater spacing for optical link can be increased to as much as 100 km (for microwave cable links, the repeater spacing is a few kilometers), though with a lower data rate.

In the Western countries optical communication links are already replacing microwave cable links, particularly on trunk lines between telephone exchanges and between cities. Submarine optical fibre cables across the Atlantic Ocean are operational for the last few years. Japan also has an extensive optical communication network and is leading the semiconductor laser technology.

In addition to transmission of data, optical information processing and optical computers are related areas where major developments are expected in the near future. Optical information processing is already in use for fingerprint identification, processing of photographs taken by satellites and high flying aircraft etc. Optical computers, based on optical bistable devices, will offer a many fold increase in the speed of computing and also the capability to do parallel processing. The first optical computer is to be demonstrated soon in Europe where its development was taken up jointly by several laboratories.

Data storage is another area where higher density of data storage is possible by using optical methods. The storage medium is generally a thin film of metal whose optical properties, such as reflectivity, gets modified when illuminated with a powerful "write" laser. The lower power "read" laser reads the change in optical property as the required information. Since laser beams can be focussed to spots smaller than one micron in diameter it takes less than one square micron to record one bit of information. ie., 100 millions bits per cm^2. Laser video disc and compact disc are examples of such data storage in the entertainment market. The density of data storage is much higher for optical data storage discs than for magnetic data storage devices. However, the main drawback of optical data storage is that, so far, it is not erasable. Several laboratories are working to develop an erasable optical data storage disc, and such erasable optical discs are expected to come in the market within the next 2-3 years.

1.5 Laser Applications in Defence

Lasers play a major role in the modern weapon systems. Laser range-finders for tanks and artillery guns measure accurately the range of targets, thus giving the tank or artillery gun first hit capability. These range-finders use the Nd:YAG laser and can measure a range of up to 10 km with an accuracy of about 5 meters.

Lasers are also used for guiding weapons to the targets. For target designation, repetitively pulsed laser illuminates the target. The target scatters the laser light and the missile seeking the scattered light homes on the target. Most of the modern fighters and bombers are equipped with laser targer designators which use Nd:YAG lasers. Another laser guided weapon is the beam riding missile. In this weapon system a laser beam is pointed to the target. The missile follows the path of the beam to hit the target. A four quadrant detector in the missile detects deviation of the missile from the laser beam path and corrects the course of the missile.

Laser ring gyroscopes have replaced mechanical gyroscopes in most of the aircraft both civil and military, and in long range guided missiles. The main advantage of a laser gyroscope is that there are no moving parts; which permit its use as a strap down gyroscope. These gyroscopes use a He-Ne laser whose resonator is in the shape of a triangle. For such a laser, the frequencies of the two laser beams, one travelling clockwise and the other anticlockwise, differ, the difference being proportional to the rate of rotation of the laser. The technical problems associated with making a laser gyroscope are very severe and require the highest level of technology to solve them.

He-Ne lasers mounted on sten guns carried by infantry permit easy aiming of the gun, thus improving its effectiveness. Similarly, He-Ne lasers, or semiconductor lasers, mounted on rifles and guns simulate the firing of the rifle or gun while training the soldiers.

Very high power lasers are being considered as weapons for destroying missiles and low flying aircraft. The SDI programme of USA, more popularly know as 'Star Wars', depends heavily on poweful lasers to destroy Soviet nuclear missiles. It is envisaged that lasers installed in an orbiting satellite should be capable of emitting beams of gigawatts of power for a few seconds to destroy such missiles. Although such lasers have not yet been demonstrated, free electron lasers (FEL), chemical lasers and gas dynamic lasers can, in principle, give the required power. Even with the *existing* high power chemical and gas dynamic lasers, low flying aircraft and stationary missiles have been destroyed in tests.

1.6 Lasers for Nuclear Energy

Nuclear reactors which use enriched uranium offer some advantages over those using natural uranium. However, enriching uranium by conventional techniques, e.g gaseous diffusion or centrifuge, is a difficult and expensive technology. Laser isotope separation (LID) promises to be a cheaper way of enriching uranium.

The physical and chemical properties of isotopes of an element are almost identical, which make separation of isotopes difficult. However, tunable narrowband lasers permit separation of isotopes by using the minute difference in the spectroscopic properties of the isotopes. The absorption lines of the two isotopes, say U^{235}, U^{238}, have slightly different wavelengths. A narrowband tunable dye laser tuned to the absorption line of U^{235} will be absorbed only by U^{235}, and not by U^{238}. The excited U^{235} atoms are ionised by irradiating them with other suitable lasers and the ions of U^{235}thus produced are collected by applications of electric and magnetic fields. The feasibility of LIS of uranium has been demonstrated in several laboratories, and USA is building a prototype production plant for enriching uranium. This plant will use tunable dye lasers pumped by copper vapour lasers for excitation and ionisation of U^{235} atoms.

Lasers are playing an important role in the search for a viable way of tapping fusion power. To obtain power from the Deuterium Tritium (DT) fusion reaction, it is necessary to heat DT to a temperature of about 100 million K and to confine the hot DT for a sufficient length of time, to permit the DT to undergo fusion reactions. There are two approaches to achieve these conditions. In magnetically confined fusion (MCF), magnetic fields are used to confine the DT plasma, whereas in inertially confined fusion (ICF), the inertia of the plasma is used to obtain to confinement. Tokamak is an example of MCF whereas laser fusion is an example of ICF. In laser fusion, a spherical glass microsphere (typically 100 microns in diameter) filled with a mixture of D and T, is irradiated symmetrically by a powerful pulsed laser. The laser heats and ablates the glass shell resulting in compression and heating of DT gas inside the shell. Several laboratories are conducting experiments with powerful Nd glass lasers to demonstrate the feasibility of the scheme. The most powerful such laser is the NOVA laser in USA which in 20 beams gives a peak power of more than 10^{13} watts in a pulse of few nanosec duration. Since such lasers are technologically difficult to build only a few countries have programmes in laser fusion research.

2 Important Lasers and Their Characteristics

Although hundreds of media have been shown to work as lasers, not all of them have been found suitable for practical applications due to one or more reasons. Given below is a brief description of only the important lasers.

2.1 Optically Pumped Lasers

In optically pumped lasers, a suitable source of light, such as an arc lamp, a flash lamp or another laser is used to excite the lasing medium. The important optically pumped lasers are Ruby laser, Nd:YAG laser, Nd glass laser and the dye laser.

Flash lamp giving a light pulse of few hundred microsec duration is used for exciting Ruby, Nd:YAG and Nd Glass lasers. The laser output normally consists of a train of random pulses of a few microsec duration and a few KWatts of peak power. However, by introducing a mechanical or electro-optic or acousto-optic shutter in the laser resonator, it is possible to obtain a single pulse of several MWatt peak power and of a few nanosec in duration. This mode of operation is known as Q-switched mode. It is also possible to mode-lock the laser to obtain ultrashort duration pulses. Mode-locked ruby and Nd:YAG lasers give pulses typically of about 100 psec in duration whereas mode-locked Nd Glass laser gives pulses as short as five picosec in duration.

The output from these lasers can be amplified to get higher powers. For most applications, one or two stages of amplifiers are adequate. However, for obtaining very high powers, e.g. for laser fusion research, a large number of amplifiers may become necessary.

The dye laser, because of its tunability, is an important tool for spectroscopy, photochemistry, pollusion monitoring, isotope separation etc. The wavelength of emission of the dye laser depends on the dye used. With different dyes one can cover the entire spectral region from near UV to near IR. Although the dye laser can be excited by special flash lamps, for most applications the dye lasers are excited by another pump laser. The pump laser can be a nitrogen laser, a frequency double Nd: YAG laser, an excimer laser, a copper vapour laser or an argon ion laser. Depending on the characteristics of the pump laser, the output of the dye laser can be continuous, pulsed with nanosec pulse duration or pulsed with picosec pulse duration.

The linewidth of the dye laser is narrowed and its wavelength tuned by incorporating a dispersive element in the resonator of the dye laser. The dispersive element is generally a diffraction grating or a birefringent Lyot filter. Tunable dye lasers pumped by argon lasers, and with linewidth of less than 1 MHz ($3x10^{-5}cm^{-1}$), are commercially available. When mode-locked, dye lasers can produce pulses shorter than a picose (10^{-12}sec) in duration which can be further compressed to give pulses as short as 6 femtosec (10^{-15}).

2.2 Electrically Excited Lasers

Electric discharge excitation is the most widely used method of excitation for gas lasers. The important gas lasers are helium-neon laser (He-Ne), helium cadmium laser, CO_2 lasers, argon and krypton lasers, nitrogen lasers, excimer laser, and copper vapour and gold vapour lasers.

Helium-neon lasers can emit laser light at several wavelengths in the visible and near infra red. The most widely used wavelength is, however, 632.8 mm in the red part of the spectrum. For applications like alignment, scanning etc. He-Ne lasers of 1 MW power are adequate. However, for some applications like holography, He-Ne lasers of up to 50 MW are used.

In a He-Ne laser, a mixture of helium and neon gases is excited by electric discharge. Helium atoms excited to metastable states, on collision with neon atoms, excite the neon atoms selectively to specific energy levels and create population inversion required for lasing. The main technological problems of He-Ne laser production relate to sealing of the windows or mirrors on the laser tube. Soft seals which use resins tend to degas and contaminate the gas mixture. Hard glass to metal seals or glass fused seals are necessary to ensure long life of the laser tube.

The helium-cadmium laser, in which cadmium is the lasing medium, emits in the violet and ultraviolet region of the spectrum at 441.6 nm and 395.0 nm wavelengths. Commercial He-Cd lasers emit power up to 100 MW in the blue and 15 MW in the violet region. In these lasers, electric discharge heats the laser tube to create cadmium vapours. The discharge excites the cadmium atoms which then emit laser radiation. While designing the laser, care has to be taken to ensure uniform cadmium vapour density in the discharge region, to prevent the chemical reaction of the cadmium vapour with components of the laser tube, and to avoid deposition of cadmium vapour on the windows of the tube.

Helium-cadmium lasers are used for holography, Raman spectroscopy, blood analysers and cell sorters, high speed printing etc.

The carbon dioxide laser is undoubtedly one of the important lasers because of its high efficiency (15%) and high power capacity. The CO_2 laser emits in the infra red at 10.6 microns. In a typical CO_2 laser, a mixture of CO_2, N_2 and He is excited by electrical discharge. Nitrogen molecules get excited by the discharge and transfer their energy to the CO_2 molecules which then emit the laser radiation. The excitation of the CO_2 laser mixture can be either pulsed or continuous.

With continuous excitation, the power available from the CO_2 laser is limited to about 75 watts per metre of laser tube length. This limit is due to the heating of the gas mixture by the discharge, which results in increasing the population of the lower laser level, thereby reducing population inversion. To circumvent this limit, the gas is made to flow at high velocity through the discharge region to carry away the heat generated rapidly. Such fast flow CO_2 lasers are now commercially available; they give up to 5 kW of continuous power.

In the pulsed mode, the pressure of the laser gas mixture can be increased to one atmosphere or even higher. Because of the higher density of molecules, it then becomes possible to obtain very high power from the laser but in a short pulse. Such lasers, known as (transversely excited atmospheric pressure) TEA CO_2 lasers, can give a peak power of a few MW in a laser pulse of 500 nsec duration.

Low power CO_2 lasers find applications in medicine, processing of ceramics, plastics, cloth etc., and in R&D. High power (above 1 KW) CWCO_2 lasers are used for processing of metals. Pulsed TEA CO_2 lasers are used for R&R in spectroscopy, photochemistry and in laser fusion research. CO_2 lasers are also being used for range-finders in defence applications.

The argon laser emits in the green, blue and ultraviolet region of the spectrum at 514 nm, 4 57 nm and 351 nm respectively. Because these lasers can give cW power of up to 20 W, they find wide use in medicine, for eye and general surgery, in Raman spectroscopy, for pumping dye lasers, and for holography. Krypton lasers also give high power, but in the red part of the spectrum. This is advantageous for some surgical procedures. Argon and krypton lasers together give the three primary colours: red, blue, green, and are used for display.

The nitrogen laser is basically a pulsed laser emitting in the ultraviolet at 336.1 nm wavelength with a typical pulse duration of 10 nsec and peak power between 100 kW -1 MW. This laser is cheap, easy to construct and does not require any imported components. This lasers is used for pumping dye lasers, and for fluorescence studies.

Excimer lasers ar powerful UV lasers which have a high efficiency (greater than 1%) when compared to other UV lasers. Excimers are molecules which exist only in the excited state and do not exit in ground state. Thus the population of the ground state of the molecule is always zero, which makes it relatively easy to obtain population inversion and to get high efficiency. The excimer molecules most widely used are XeF emitting at 351 nm, XeCl emitting at 308 nm, KrF emitting at 248 nm and ArF emitting at 193 nm. Typical peak powers of 10-20 MW, typical pulse durations of 30-50 nsec and typical pulse repetition rates of 10-100 pps are available in commercial models.

Excimer lasers are used to pump dye lasers, for spectroscopy and photochemistry, in medicine for surgery, and in material processing applications.

The Copper Vapour Laser (CVL) is another efficient laser (1%

efficiency) emitting at 511 nm and 578 nm in the green and yellow respectively. In a CVL, discharge in Helium gas, filled in alumina laser tube, heats the tube to about 1500°C. At this temperature, copper placed in the tube evaporates. The copper atoms of the vapour are excited by the discharge and emit laser radiation. Commercially available CVLs give average power of up to 40 watts, peak power of up to 100 kW, in a pulse of 30 nsec duration, and at repetition rates of upto 10 KHz.

Copper vapour lasers are widely used to pump dye lasers, for spectroscopy and photochemistry, for high speed photography, and for laser displays etc.

When copper is replaced with gold, one gets the gold vapour laser (GVL) which emits a red beam at 628 nm. This laser is important for photoradiation therapy for cancer treatment.

2.3 Semiconductor Diode Lasers

Semiconductor lasers are unique because of their small size (smaller than 100x100 micron), their high efficiency (nearly 50%) and the possibility to modulate the light directly by modulating the current through the laser. All of these properties are important for optical fibre communication and hence semiconductor diode lasers are universally used for optical communication. The wave length of emission of the semiconductor laser depends on the chemical composition of the semiconductor and the temperature of operation. The first generation of optical communication links used GaAlAs semiconductors for lasers, emitting at 0.92 micron because the technology of GaAIAs lasers was more advanced then. However, the lasers for the next generation of communication are required to emit at a wavelength of 1.3 micron or 1.55 micron where the fibre dispersion and absorption are respectively the least. By suitably adjusting the ratio of In, GaAs and P in the quaternery compound, InGaAsP, it is possible to obtain lasers operating at these wavelengths.

Another group of semiconductors, namely lead salts (II-IV compounds), are used to make laser diodes which, depending on the composition, emit in the wavelength range of 4 microns to 40 microns. A diode of particular composition can be tuned over a small wavelength region by changing its temperature. These lasers are used mainly for spectroscopy, pollution measurement etc.,

Semiconductor lasers working at shorter wavelength extending in the red are now available. Lasers emitting at about 0.8 micron find applications in laser printers and scanners. Optical disc readers, and related applications.

Semiconductor diode lasers emitting in the red have been demonstrated in laboratories in Japan and are expected to be commercially available within next 2-3 years. They will then replace the He-Ne laser in most applications.

3 Status of Laser Technology in India

3.1 Historical Background

The importance of lasers was recognised by the scientific community in India fairly early and several institutions such as BARC, NPL, IIT, Kanpur and IISc initiated R&D programmes, although modest ones, in this area in the mid-sixties. The first laser fabricated in India was a gallium arsenide semiconductor laser, developed at BARC in 1964. Although the GaAs slice for making this laser was imported, the entire processing of the laser diode, which included forming the p-n junction, forming ohmic contacts and forming the resonator by appropriate cleaving of the slice, was developed at BARC. This laser was used in 1965-66 to establish an optical communication link between BARC and TIFR, a distance of 20 km. In 1964-65, IIT, Kanpur, imported a ruby laser from USA and conducted some studies on the characteristics of the laser. This laser was later used for studying Raman scattering.

The Indian programme of laser R&D was soon expanded. In 1967-68 BARC undertook the development of several other lasers: ruby, Nd glass, CO_2 and He-Ne. The ruby laser was operated in 1968 and was used in the first rangefinder developed at BARC in 1969-70.

IISc and NPL also took up the development of the He-Ne laser in 1966-67. The operation of indigenously built He-Ne lasers was more or less simultaneously demonstrated by BARC, NPL and IISc. While BARC discontinued further work on He-Ne lasers then (although it was taken up later again), and concentrated on solid state lasers and CO_2 lasers, NPL and IISc continued their efforts to develop the know-how for the He-Ne laser. The know-how was transferred by NPL to a private sector manufacturer, and by IISc to ECIL, around 1974-75.

Since the sixties the laser and related R&D programmes have expanded considerably and today encompass many of the important areas of laser applications. However, compared to the magnitude of similar efforts in Western countries, or even in China, Indian efforts are very modest. Even then, Indian scientists have been able to make their mark in the international scene in some of these areas.

3.2 Laser Technology in India

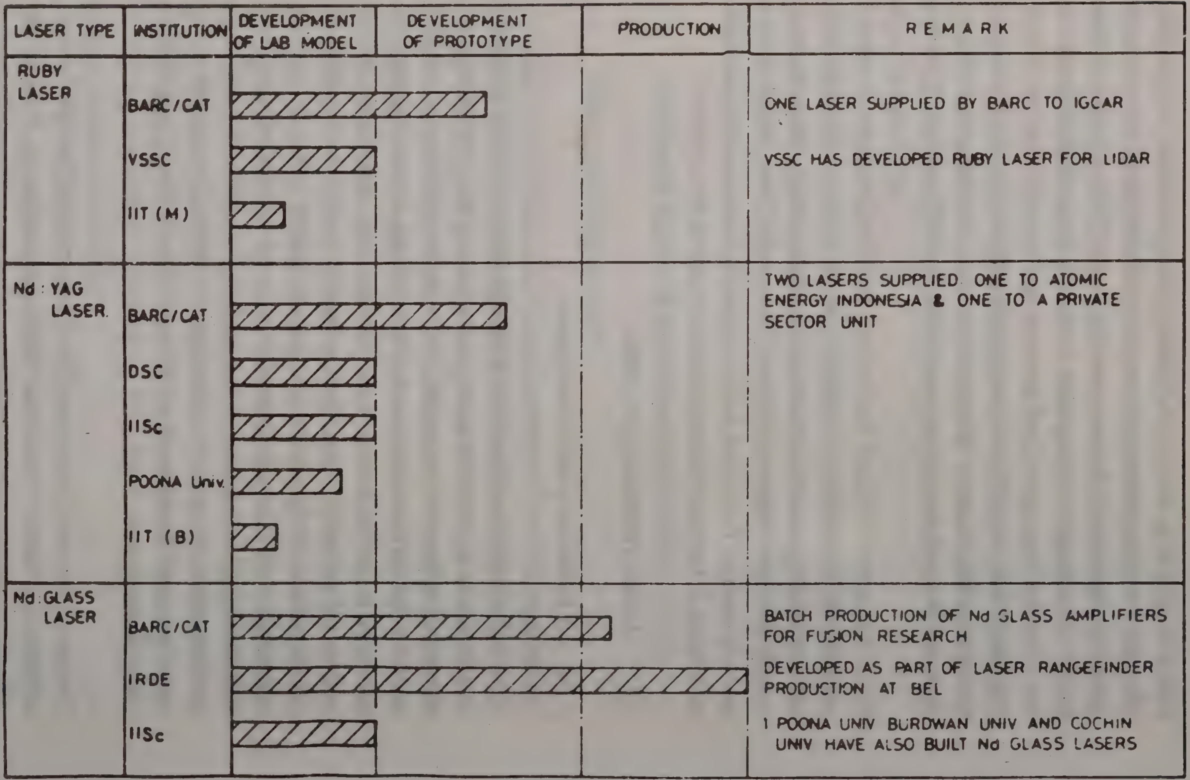
3.2a A Laboratory-wise Description

Although today a large number of laboratories have R&D programmes in lasers and related areas, the work on the development of technology of lasers is very small. It is important at this stage to define what one means by development of technology. Several laboratories have built lasers for their own use. In most cases these lasers are not engineered properly. Such lasers generally cannot be operated by anyone other than the person who has developed it. For the purpose of this report such development efforts are not considered to be taken as technology development. In the bar chart (Table 1) which indicates the status of technology of various lasers in India, laboratories which have developed lasers, but not engineered them properly, are listed in the remarks column.

The laboratory with the largest effort for developing laser technology in India is. BARC. The laser R&D programme at BARC was expanded systematically to cover development of many important lasers. These include He-Ne laser, He-Cd laser, N_2 laser, Ar laser, CO_2 laser, copper vapour laser, ruby laser, Nd:YAG laser, Nd glass laser

Table 1

The Status of Laser Technologies in India



LASER TYPE	INSTITUTION	DEVELOPMENT OF LAB MODEL	DEVELOPMENT OF PROTOTYPE	PRODUCTION	REMARK
RUBY LASER	BARC/CAT	▨	▨		ONE LASER SUPPLIED BY BARC TO IGCAR
	VSSC	▨			VSSC HAS DEVELOPED RUBY LASER FOR LIDAR
	IIT (M)	▨			
Nd : YAG LASER	BARC/CAT	▨	▨		TWO LASERS SUPPLIED ONE TO ATOMIC ENERGY INDONESIA & ONE TO A PRIVATE SECTOR UNIT
	DSC	▨			
	IISc	▨			
	POONA Univ.	▨			
	IIT (B)	▨			
Nd:GLASS LASER	BARC/CAT	▨	▨		BATCH PRODUCTION OF Nd GLASS AMPLIFIERS FOR FUSION RESEARCH
	IRDE	▨	▨	▨	DEVELOPED AS PART OF LASER RANGEFINDER PRODUCTION AT BEL
	IISc	▨			1 POONA UNIV BURDWAN UNIV AND COCHIN UNIV HAVE ALSO BUILT Nd GLASS LASERS

Table 1 (*Contd.*)

LASER TYPE	INSTITUTION	DEVELOPMENT OF LAB MODEL	DEVELOPMENT OF PROTOTYPE	PRODUCTION	REMARK
He-Ne LASER					
	BEL	▨	▨	▨	2 mW 632·8 NM LASERS UNDER PRODUCTION HARD SEAL TECHNOGY YET TO BE DEVELOPED
	NPL	▧	▧	▧	KNOWHOW TRANSFERRED TO PRIVATE SECTOR UNIT. DEVELOPMENT AND PRODUCTION DISCONTINUED.
	IISC	▧	▧	▧	KNOW-HOW TRANSFERRED TO ECIL. DEVELOPMENT AND PRODUCTION DISCONTINUED
	BARC	▨			LAB MODELS OF UPTO 50MW. POWER
	IGCAR	▨			50 mW. POWER LAB MODEL
	IAT	▨			50 mW. POWER LAB MODEL
	IIT (K)	▨			
ARGON LASER					
	BARC	▨			4 WATT ARGON LASER
	IIT (K)	▨			300 mW ARGON LASER

Table 1 (*Contd.*)

LASER TYPE	INSTITUTION	DEVELOPMENT OF LAB MODEL	DEVELOPMENT OF PROTOTYPE	PRODUCTION	REMARK
CO_2 LASER UPTO 100W	BARC/CAT	▨	▨	▨	KNOWHOW TRANSFERRED TO CEL. PRODUCTION DISCONTINUED. DEVELOPMENT CONTINUES.
	JYOTI LTD.	▨	▨	▨	DEVELOPMENT & PRODUCTION DISCONTINUED.
					SEVERAL OTHER LABORATORIES NAMELY IIT(K), IISc, IIT(M), BHU, POONA UNIV. HAVE BUILT SUCH LASERS
CO_2 LASER FAST FLOW 1KW	BARC/CAT	▨			
CO_2 LASER PULSED TEA	BARC/CAT	▨	▨		IRDE AND POONA UNIV. HAVE ALSO BUILT SUCH LASER.
CO_2 LASER GAS DYNAMIC	DSC	▨			
DYE LASER	BARC/CAT	▨	▨		SEVERAL OTHER LABORATORIES NAMELY COCHIN UNIV., IIT(B), IIT(K), IIT(KH) HAVE ALSO BUILT DYE LASERS.
	BHU	▨			
	POONA UNIV.	▨			
He-Cd	BARC	▨			100 mW OUTPUT POWER
	IGCAR	▨			

Table 1 (*Contd.*)

LASER TYPE	INSTITUTION	DEVELOPMENT OF LAB MODEL	DEVELOPMENT OF PROTOTYPE	PRODUCTION	REMARK
NITROGEN LASER	IIT (K)	▨	▨	▨	KNOW-HOW TRANSFERRED TO CEL DEVELOPMENT AND PRODUCTION DISCONTINUED.
	BARC/CAT	▨	▨		
	BHU	▨			SEVERAL OTHER LABORATORIES INCLUDING COCHIN UNIV. KARNATAK UNIV. MARATHWADA UNIV. POONA UNIV. M. DAYANAND UNIV. IIT(B), IIT (KH) HAVE ALSO BUILT N_2 LASERS
	ANNA UNIV.	▨			
SEMICONDUCTOR LASER	SPL	▨	▨		EXACT STATUS NOT KNOWN
EXCIMER LASER	IIT (K)	▨			
	BARC/CAT	▨			
COPPER VAPOUR LASER	BARC/CAT	▨	▨	▨	BATCH PRODUCTION UNDERTAKEN AT CAT.
	IIT (K)	▨			WORK DISCONTINUED.

and dye laser. Some amount of engineering has gone in all of them and several of them have been supplied to other laboratories where their performance has been satisfactory. Even then it is considered necessary to do further prototype development for some of these lasers before the technology is ready for production.

BARC has developed, with assistance from IAT, a 50 MW laser for Raman spectroscopy. Similarly, a 100 MW He-Cd and a 4 W argon laser were developed for the same application. The design of the Hw-Ne and He-Cd lasers were given to IDCAR when these lasers were successfully built.

BARC has developed various types of CO_2 lasers. The know-how for a 100 watt CO_2 laser, which had options for pulsed operation and tunability, was given to CEL. As a part of the know-how, two CO_2 lasers were fabricated by BARC and given to CEL. These lasers were supplied by CEL to two laboratories and are operating successfully. Due to a lack of demand, CEL has discontinued production of this laser.

BARC has also worked extensively on the technology of pulsed TEA CO_2 lasers. A number of such lasers have been built and are used in BARC. The most recent development is a high rep. rate TEA CO_2 laser which gives 1 joules 3 MW pulses at 50 pps.

BARC has also worked extensively on the technology of solid state lasers, namely, ruby laser, Nd:YAG laser and Nd glass laser. Several such lasers have been built and supplied to other users. BARC is currently building a four beam 1000 joule, 1 terawatt (10^{12}watts) Nd glass laser for fusion studies. The technology of dye lasers, pumped by N_2 laser and CVL, has also been developed at BARC. A line width of 0.00 cm^{-1}, and an efficiency of 12%, from Rn6G dye laser pumped by CVL has been achieved. Frequency stabilisation of dye laser has also been developed. Two such lasers have been supplied to other users in BARC, where the performance has been satisfactory.

BARC had recognised lasers as a thrust area and had planned to expand the work in a big way. Due to some limitation at BARC for such expansion, DAE considered it necessary to establish a new R&D Centre for expanding their laser programme. The Centre for Advanced Technology (CAT) was thus established and some of the laser programmes of BARC were shifted to this Centre in 1986. Gradually, most of the laser development programmes at BARC will be shifted to CAT.

CAT has planned an extensive programme on laser development and engineering. It is also proposed to undertake limited scale production of lasers and laser instruments if there is demand for supply of such items. The work in CVL was transferred from BARC to CAT in 1986. After further engineering development on the laser, CAT has taken up batch production of 10 W CVL. A laboratory model of a 35 W CVL is already operational and the development of 100 w cul is in progress. It may be mentioned that CVL became commercially available in the Western countries only about 5-6 years ago. The specifications of CVL developed at CAT match those of commercial models.

Work on technology of higher power CO_2 lasers, medical CO_2 lasers and nitrogen lasers has also been started and fully engineered *prototype models will be developed over the next 2-3 years. The CAT programme includes development of prototype, and if necessary, limited scale production of copper vapour lasers, nitrogen lasers, excimer lasers, dye lasers, CO_2 lasers - low power cw, high power cw and TEA pulsed, Nd:YAG lasers, Nd glass lasers and laser instruments for R&D, medicine and industry.

DRDO also has major programmes to develop laser technology specifically for defence applications. Most of this work is carried out at DSC, SPL and IRDE. IRDE has developed laser range-finders for tanks which use Q-switched Nd: glass lasers. The Nd: glass laser developed by IRDE for this purpose uses a rotating prism Q-switch and gives a 30-40 nsec pulse of 1-2 MW peak power (exact specifications are not known). This technology has met defence specifications and has been transferred to BEL for production. Due to its long wavelength, CO_2 lasers offer some advantage over Nd:YAG lasers for applications such as ranging and target designation. IRDE has developed a cw waveguide CO_2 laser.

DSC has been identified by DRDO as the laboratory to develop laser components and basic lasers. A light weight Q-switched Nd: YAG laser giving 120 mJ in 20 nsec, i.e 6 MW peak power at a pulse repetition rate of 20 pps, has been developed. DSE has also undertaken development of high power CO_2 lasers.

SPL is developing laser materials and semiconductor lasers. It has excellent facilities for growing crystals by several techniques and has been successful in growing Nd:YAG crystals and GaAs crystals. The technology of GaAs lasers is also being developed at SPL but the exact status is at present not known.

IIT, Kanpur, was perhaps the first academic institution in India to start work in the area of lasers. Initial work was carried out with a ruby laser imported from USA. However, later development of various lasers was also undertaken. The lasers developed included the He-Ne laser, low power cW CO_2 laser, which was used for study of chemical kinetics, and the copper laser. Later, under a project from DST, the technology of the Nitrogen laser was developed and the know-how, has transferred to CEL. The laser design was based on indigenous components only. In particular, a spark gap was used in place of a thyratron. This made the operation somewhat unreliable. CEL later discontinued production of this laser. Under another project, IIT, Kanpur, has developed a low power, i.e.,300 MW argon laser. The know-how for this laser is not yet ready for production. More recently IIT, Kanpur, has taken up the development of excimer lasers. There are also plans to take up development of the He-Ne laser and the waveguide CO_2 laser.

IISc, Bangalore, also started working in the area of laser development fairly early, when work on He-Ne laser was initiated. Then, along with the development of the He-Ne laser, work on thedevelopment of laser mirrors was also taken up. The technology of the He-Ne laser, developed at IISc, was transferred to ECIL in the mid-seventies, and ECIL soon started production of these lasers. The laser was an external mirror laser which required windows on the laser tube. These windows were sealed with resin, i.e., soft sealed. The performance of these lasers, particularly tube life, was somewhat unsatisfactory and

ECIL discontinued production of this laser.

IISc also developed the Nd:YAG laser operating in the normal mode and giving 100 mJ energy per pulse at 20 pulses per second. Similarly, a low power CO_2laser and Nitrogen laser were also built. The Aerospace Engineering Department of IISc is using shock tubes to make a parametric study important for designing the gas dynamic CO_2 laser.

NPL also started development of He-Ne lasers in the early seventies. The He-Ne laser tube developed by them had the mirrors fixed directly on the laser tube, thus eliminating the need for windows. Such a tube, though more difficult to fabricate than the one with windows, offers the advantage of being mechanically more stable. The know-how of this laser was passed on to a private sector manufacturer. Unfortunately, in this case also, the tube life was unreliable, presumably because of the soft seals used, and hence production has to be discontinued. NPL is now working on frequency stabilisation of He-Ne lasers for use as time and length standards.

Bharat Electronics Limited (BEL), at Bangalore took up the development of He-Ne lasers independently. Their laser tube also uses soft seals for the mirrors. BEL claims that the life of the tube is adequate. BEL lasers purchased by BARC have been working satisfactory. The production equipment for these lasers has been shifted to the BEL, Pune unit, but regular production has yet to commence. BEL is hesitant to take up regular production of He-Ne lasers unless there is an adequate demand. It is understood that BEL will undertake production only if the demand is at least 500 lasers per year or if it is instructed by higher authorities to take up this production, irrespective of economics.

Jyoti Ltd at Baroda was the only private sector undertaking which had a R&D programme to develop laser technology. Jyoti developed a low power (50 watt) CO_2 laser and also offered a work station for use with their laser. It is understood that only two CO_2 lasers were sold by Jyoti. Jyoti also was making laser aligning systems which used imported He-Ne lasers. They have sold more than 50 laser alignment systems. Unfortunately, due to poor demand, Jyoti has discontinued the production of CO_2 lasers as well as their R&D programme on lasers.

Defence Metallurgical Research Laboratory (DMRL), Hyderabad is engaged in a R&D programme aimed at the development of new materials and processes for both defence and other applications. DMRL has recently set up a Laser Processing Laboratory. The facilities include a 5 KW CO_2 (continues wave)high power laser and a 400 watt Nd YaG solid state laser. The 5 KW high power laser (the only unit at present in our country) is required for modifying the surfaces of materials to improve the resistance to wear, erosion and corrosion. The Nd YaG pulsed laser is suitable for drilling fine holes, and for obtaining rapidly cooled surfaces with enhanced properties. With the above facilities, it is possible to carry out a wide range of R&D activities in the area of materials processing.

Efforts are underway to improve the surface hardness and wear resistance of steels by melting or by transformation hardening and titanium alloys by gas alloying with N_2 to produce TiN coatings. The lasers will also be used to remelt the plasma sprayed coatings to make them defect free. Work is in progress to treat a range of ceramic materials to prdict the resulting microstructures and to correlate the same with properties. DMRL is also developing an understanding of the process of drilling using the laser to drill cooling holes in turbine blades and exploring new processes such as laser evaporated coatings, laser cladding.

The description given above of laser technology development in India was laboratory-wise. It is worthwhile to put the same information in a different way to see where we stand as far as technology of different lasers is concerned.

3.2b A Description in Terms of Different Lasers

He-Ne Laser

- The technology of 2 MW He-Ne lasers has been developed at

NPL,IISc and BEL. NPL and IISc technologies were transferred respectively, to a private manufacturer and to ECIL. Due to the unsatisfactory life of the laser tube both have discontinued production.

- BEL has transferred its He-Ne production facility to BEL, Pune. However, it is understood that the routine production of He-Ne lasers will be undertaken only if there is an adequate market (of about 500 lasers) per year.

- NPL is now developing frequency stabilised He-Ne lasers for frequency and length standards.

- BARC, with help from IAT, has fabricated a 50 MW He-Ne laser which can be used for holography or Raman spectroscopy. The laser is only a laboratory model but can be developed as a prototype model. Frequency stabilised He-Ne lasers have also been developed at BARC.

- IIT, Kanpur, had also developed the He-Ne laser, going up to 10 MW power, but later discontinued the work. It is now proposed to take up the development of He-Ne laser technology again at the IITs Centre for Laser Technology.

- Other laboratories/institutions which have fabricated He-Ne lasers are IGCAR, IAT.

Argon Laser

- The argon laser development was taken up at IIT, Kanpur in 1974 and a 300 MW laser was built in 1981. This is a laboratory model and considerable work will have to be done to bring it to production.

CO_2 Laser

Low Power CW CO_2 Laser

- A 100 watt CO_2 laser was developed at BARC and the know-how was transferred to ECL. Due to inadequate demand, CEL discontinued production of this laser. Two units, supplied by BARC along with the know-how, were supplied to two laboratories and are working satisfactorily. BARC has also fabricated a few such lasers for other laboratories.

- The work on developing low power CO_2 lasers, suitable for medical applications, is now transferred from BARC to CAT.

- Jyoti Ltd, Baroda, developed, and put into production, a 50 watt CO_2 laser. Only 2 lasers could be sold. Due to inadequate demand the production has been discontinued.

High power (greater than 1 kw) CO_2 laser

- CO_2 lasers capable of giving more than 1 kw of power are being developed at CAT and BARC, BARC is developing a fast axial flow CO_2 laser whereas CAT is developing a fast transverse flow CO_2 laser. 500 watt units are expected to work by mid-88 and the 1 kw unit by mid-89. CAT has plans to properly engineer both the versions of the 1 kw CO_2 laser and, if required, undertake limited production.

Pulsed TEA CO_2 laser

- BARC has worked extensively on pulsed TEA CO_2 lasers. Several TEA CO_2 lasers and amplifiers have been built for experiments in BARC. Wavelength tunable TEA CO_2 lasers have also been developed. More recently, a 1 joule per pulse, 50 pulses per sec TEA CO_2 laser has been developed. Such lasers can find applications in medicine, industry as well as in R&D.

Gas dynamic CO_2 laser

- DSC has recently started a programme in this area.

Nitrogen laser

- IIT, Kanpur, has developed the technology of the N_2 laser and transferred the know-how to CEL. The design was based on indigenous components and avoided components such as thyratrony. This made the operation unreliable. CEL discontinued production after selling about 5 units.

- BARC/CAT have also developed Nitrogen lasers of several designs. The recent design using ceramic capacitors and thyratron has a performance similar to commercial N_2 lasers made in Western countries. The programme at CAT is now to develop N_2 lasers and N_2 laser based instruments.

- Other laboratories which have put in considerable effort to develop the N_2 laser are BHU, Anna University, Marathwada University and Poona University.

Copper Vapour Laser (CVL)

- BARC started development of CVL in 1983 and operated the first CVL at low rep. rates in 1985. A 100 kW peak power, 10 watt average power, 5 KHz CVL was later developed. This work was shifted to CAT in 1986. At CAT proper engineering of the 10 watt CVL was carried out and batch production undertaken. Simultaneously a 30 watt average power CVL was developed. Work is being done to engineer this model and to develop a 100 watt CVL.

Excimer Lasers

- IIT, Kanpur, and CAT have programmes to develop excimer lasers. The first excimer laser developed at CAT will become operational in 1989.

Helium Cadmium Laser

- BARC has developed a 100 MW He-Cd laser for Raman spectroscopy. With assistance from BARC, IGCAR has also built a similar laser. The technology will need further development to bring it to the level of production technology.

Dye Laser

- BARC has developed dye lasers pumped by N_2 laser and CVL. The specifications are close to those of similar lasers commercially available. BARC has also developed frequency stabilisation for these lasers. Three dye lasers have been built and are in regular use at BARC for spectroscopy experiments.

- CAT is taking up the development of dye lasers and amplifiers to obtain higher power from the dye lasers.

- Other laboratories which have built dye lasers are the IITs at Kanpur, Bombay and Kharagpur, BHU, Poona University, Anna University, and Cochin University.

Ruby laser, Nd:YAG laser and Nd:YAG Glass Laser

- The technology of all the three lasers is similar and a laboratory which has developed one laser can, with suitable modifications, build the other.

- BARC has an extensive programme to develop all the three lasers. The ruby laser was first built and operated in BARC in 1968. This laser was later used for developing a laser photocoagulator and a range-finder. A 25 joule per pulse ruby laser has been supplied to IGCAR.

- A Nd: YAG laser operating in the normal mode and, the Q-switched mode at low rep. rate, was developed at BARC in the mid-seventies. One laser was supplied to Atomic Energy, Indonesia and one to a manufacturer of precision electrical instruments.

- Nd:YAG lasers operating in normal mode and Q-switched mode up to 50 pulses per second have been developed by DSC.

- IISc has developed cw Nd:YAG laser pumped by Kr Arc lamp.

- Poona University and IIT, Bombay, are developing Nd:YAG-lasers under projects funded by DST.

- Extensive work on development of Nd Glass laser has been carried out at IRDE and BARC. IRDE has developed Q-switched Nd: glass lasers for range-finders. These are now being produced by BEL.

- BARC is building a four beam 1 kJ, 1 nsec, 1 Twatt (10^{12} watts) Nd glass laser for laser fusion research. This laser consists of a laser oscillator followed by 18 amplifiers. The Nd Glass oscillators/amplifiers range in size from 5 mm dia to 100 mm dia. A number of them have been batch produced for this laser.

Semiconductor lasers

Although semiconductor lasers are among the most important lasers, only one laboratory, SPL, is today developing them in India. This is perhaps because of the large investment in equipment necessary to undertake a meaningful programme.

3.3 Laser related R&D in India

In the previous section, only work relating to laser technology *per se* was described. It is worthwhile to review Indian work in laser related areas, e.g. applications of lasers, laser physics, laser components, development etc. For this purpose, a report prepared for INSA, entitled "R&D in lasers and related areas in India during 1985", is reproduced below:

Introduction

Laser related activities, including R&D work as well as applications, are, at present, fairly widespread in India covering several national laboratories, IITs and universities. In this report, based on work performed in various laboratories during 1985, an attempt is made to convey the range and nature of these activities. The report must, however, be considered as illustrative, rather than exhaustive.

Laser Research and Development

Laser R&D work is in progress in various laboratories such as those at BARC, IISc., DSC, IITs at Kanpur, Delhi, Madras and the universities of Bombay, Cochin, Banaras, Karnataka etc.,

At BARC, a high rep.rate (5 KHz) copper vapour laser emitting an average power of 15 W was developed and this has bn/n-d to pump a dye laser which gives an average power of 1.5 W with a spectral linewidth of 0.06 cm^{-1}. A CO_2 laser pumped CF_4 laser was developed giving up to 20mJ energy per pulse at 16 um. A cW CO_2 laser was frequency stabilised to give a frequency stability of 1 MHz. The high power Nd glass laser produced 80 J energy in 20 ns pulses from oscillator and four amplifier sections.

At DSC, a light weight high rep. rate (20 Hz), Q-switched Nd: YAG laser generating 120 mJ, 20 ns pulses has been developed. At IISc, gain optimisation of gas dynamic CO_2 lasers and characteristics of synchronously modelocked dye lasers were studied theoretically. At Bombay University, a pyrozolo derivative of coumarin was found to have a comparable performance to that of standard dyes as a laser medium. AT IIT, Kanpur, a plasma recombination laser is being developed using a simple capacitor discharge and sealed discharge tube.

Work on growth of laser-related materials and fabrication of optical components is being carried out at BARC, CGCRI, NPL, DSC and IIT, Kanpur. AT BARC, crystals of alkali halides, KDP and lead germanate were grown and characterised. AT CGCRI, a lithium calcium silicate glass doped with 3% neodymium oxide was developed having platinum impurity content less than 2 ppm. At DSC, crystals of YAG and $LinbO_3$ as well as laser glasses were grown and processed. At NPL, various components such as interference filters, neutral density filters etc. were designed and fabricated for use in Rohini and Bhaskara satellites.

Quantum and nonlinear optics

Research groups working in these areas are those at University of

Hyderabad, BARC, IACS, IIT, Delhi and the universities of Burdwan and Calcutta.

At University of Hyderabad, it was shown that the dispersive properties, and hence the efficiency of VUV generation from atomic vapours, can be controlled by strongly driving a suitably chosen resonant transition. It was also shown that pressure induced resonances can be observed in fluorescence. A simple theoretical model was successfully used to explain the reported shift in surface plasmas dispersion due to its interaction with localised plasmas. At BARC, effects of cavity damping on vacuum field ruby oscillations of a two-level atom in a cavity were studied by deriving exact quantum electrodynamical results. The formalism used for treating two-level atoms extended to multilevel quantum systems. For optical double reasonance in a three-level system, fluorescent spectra and intensity correlations were obtained analytically in the intense field limits. At IACS, it was shown that the route to chaos in stimulated Raman scatter is a series of period doubling bifurcations. It was also shown that dipole-dipole interaction between atoms changes the nature of co-operative interaction between a collection of two-level atoms confined in a small volume.

Lasers in Research

The main areas in this category are laser-plasma interaction, laser photochemistry and laser spectroscopy, including laser Raman scattering.

Laser-Plasma interaction is being studied at BARC using the high-power Nd:YAG laser. In experiments on hydrodynamics of laser irradiated thin targets, it was observed that a gold coating on the front target surface reduced the effect of non-uniform laser illumination on uniformity of target acceleration, without a significant change in hydrodynamic efficiency. This result has been attributed to the istropic transport of energy due to soft X-rays produced in the gold plasma.

Some of the prominent groups involved in research in photochemistry are those at BARC, IACS, TIFR and BHU. At BARC, selective decomposition of CDF_3 in CHF_3 was observed using a CO_2 laser with a selectivity 40. Also selective enhancement of the ionization reaction $U+O_2 = UO_2+e^-$ was investigated using an Ar^+ laser pumped dye laser. At IACS, a mode-locked dye laser was used for studying various molecular problems such as excited state proton transfer, dynamics of exciplex formation, conform relaxation in the excited state and infra-molecular radiationless transition. In TIFR, a time-domain EST spectrometer was used to study the spin dynamics and chemical kinetics in laser induced formation of free radicals. In BHU, N^2 laser irradiation has been used for studying problems in solid state physics, molecular physics, organic chemistry etc. In BARC, laser Raman study of antimony revealed the existence of an asymmetric phonon lineshape arising from coupling of the optical phonon and intraband electronic transitions within the penetration depth of the metal. Also measurments, of rotation-vibration bands in CH_3I, were performed to obtain the time correlation function corresponding to reorientational motion in liquids. At IIT, Kanpur, laser Raman scattering was used for studying structural phase transformations in various solids, while at NEHU, resonance Raman scattering was used for studying structures of various organic molecules and some biological systems. Orientational dynamics of molecular ions in solids and vibrational relaxation mechanisms in liquids were also investigated at NEHU. At Kurukshetra University, vibrational spectra of methyl and halogen alkanes were studied at ambient and low temperatures.

Other laser based spectroscopic techniques, employed by various groups, are photo-acoustic and optogalvanic spectroscopy, laser-induced fluorescence and ionisation, saturation spectroscopy etc. At BARC, three-step photoionisation of uranium atoms was studied and was found to produce 5-10 times enhancement in yield compared to the use of only a single laser. The CO_2 laser induced IR fluorescence of SF_6 and CF_2Cl_2 was also investigated; This revealed the existence of a double exponential decay. AT TIFR, a time-correlation single photon counting system, with a synchronously pumped mode-locked dye laser, has been assembled for psec studies. At IIT, Kanpur, laser-induced fluorescence was used for investigating spectra of rare earth ions doped in Scheelite type crystals, while, at IACS, two-photon fluorescence has been studied to understand exciton splittings in bimolecules and two-photon spectra of lanthanide ions. At Indira Gandhi Centre for Atomic Research, Rayleigh scattering of the He-Ne laser beam is being used for studying the structure and dynamics of colloidal suspensions of polystyrene particles.

Laser applications

Various applications of lasers are being pursued in the fields of communication, holography, machining and material processing, and in medicine for diagnostic as well as surgical purposes.

Communication and Holography Work on optical communication is going on at the IITs and IISc. At IIT, Madras, an atmospheric IR computer link has been established using GaAlAs lasers and the feasibility of underwater communication using blue/green laser is being investigated. Various aspects of fibre-optic communication such as component development, characterisation etc. are also being studied. At IIT, Kanpur, a 5 km long repeaterless fibre-optic digital communication link, for data rates in excess of 10 Mb/s, has been developed and tested. An analog video link of similar length has also been developed and tested. At IIT, extensive research work is being performed in the areas of wave propagation in fibres, integrated optics, fibre optic sensors etc.

At IIT, Madras, holographic interferometry is being developed for stress analysis while at NPL, a real-time holographic interferometer has been set up for sensing temperature. At Cochin University, a holographic table based on a new design has been fabricated and tested.

Industrial and medical applications Application of lasers to machining and material processing is being investigated at BARC, and at IIT, Madras.

At BARC, a CW CO_2 laser was used for the machining and processing of various polymers. It was found that the tract revelation sensitivity of a widely used particle track detector, CR-39, increases significantly on treating with CO_2 laser radiation at a fluence of 30 J/cm². It was also shown that surface hardness of CR-39 sheet can be reduced by 40% without affecting its bulk properties by irradiation at a fluence between 9 and 25 J/cm². Another interesting result was that the highly combustible cellulose nitrate polymers can be safely processed in air with a CO_2 laser. At IIT, Madras, a CO_2 laser was used for drilling holes in materials such as hylam, perspex and plywood using a numerically controlled microprocessor based compound sliding table and the feasibility of laser dressing of grinding wheels, using a Nd:YAG laser, was investigated.

At IIT, Madras, laser speckle interferometry is being used for monitoring chest wall movement which, in turn, gives information, about cardiac displacements, that is helpful in diagnosing various ailments. Reflectance of tissues and blood samples for He-Ne laser emission are also being studied and the results so far show that the reponse of healthy and diseased tissues is quite different. At BARC, a programme for the use of CO_2 lasers in surgery has been initiated.

Concluding remarks

This brief report illustrates the work performed in areas of lasers and related fields at various research centres in India. As a rough pointer to the strength of the research work, Table 2 shows the number of publications in various sub-fields which appeared in refered national and international journals during 1985.

Table 2
Number of publications in various sub-fields during 1985

	Field	Number of publications
1	Laser R&D	22
2	Quantum and Nonlinear Optics	15
3	Laser in Research	20
4	Communications and Holography	18
5	Industrial and Medical applications	5

3.4 Development of Laser Components in India

Many of the lasers developed in India, and described earlier, depended on imported components. Hence, while discussing the status of laser technology in India, it is necessary to also discuss the status of laser component development in India (see Table 3).

Laser crystals/glass Ruby, Nd:YAG and Nd Glass are the active media for the lasers. Nd Glass has been developed by CGCRI and is being supplied by them in limited quantity. Development of better quality Nd Glass is going on.

Nd:YAG is being grown at SPL and BARC.SPL has made laser quality rods from Nd:YAG boules grown by them.

There is currently no work on growing ruby crystals in India.

Nonlinear crystals For Q-switching, harmonic generation, and other nonlinear optical applications, nonlinear crystals such as ADP, KDP, $LiNbO_3$ etc. are required. BARC has grown ADP/KDP crystals and has made Q-switches and harmonic generators. SPL, BARC, IISc have grown $LiNbO_3$ crystals. IIT, Kanpur, has also grown KDP/ADP crystals.

Although these laboratories are developing the technology of growth of these crystals, it is not yet available to users.

Mirrors These are several institutes and private manufactures who have the capability to polish laser mirror substrates. The quality is acceptable for most of the applications.

Coating of laser mirrors requires a substantial capital investment. Several laboratories have imported such equipment and are developing the technology of coating multilayer dielectric mirrors. These include IISc, BARC, DSC, NPL, CSIO, BEL etc. Several other public and private sector units have also set up facilities for coating, but generally not for laser mirrors.

NPL, IISc, BARC, CSIO and DSC have developed laser coating for lasers in the visible and in the IR up to 1.06 microns. There is no systematic testing of these mirrors hence it is not possible to comment on their quality. However, for all but the most stringent requirement, these mirrors will function satisfactorily.

Mirrors for CO_2 lasers require a different substrate, ZnSe or Ge, the former being preferred for most applications. There is no work on developing ZnSe in India. USA has put an export embargo on large diameter ZnSe optics. There is also no work on developing CO_2 laser coating in India.

Flash Lamps Flash lamps are essential for pumping ruby, Nd:YAG and Nd glass lasers. BARC has developed flash lamps of various sizes and specifications suitable for this purpose. Batch production has been taken up and many flash lamps have been supplied to users in BARC and other laboratories.

Gratings Gratings are used for tuning the wavelength of lasers. Generally ruled gratings are used for CO_2 lasers and holographic gratings for dye lasers.

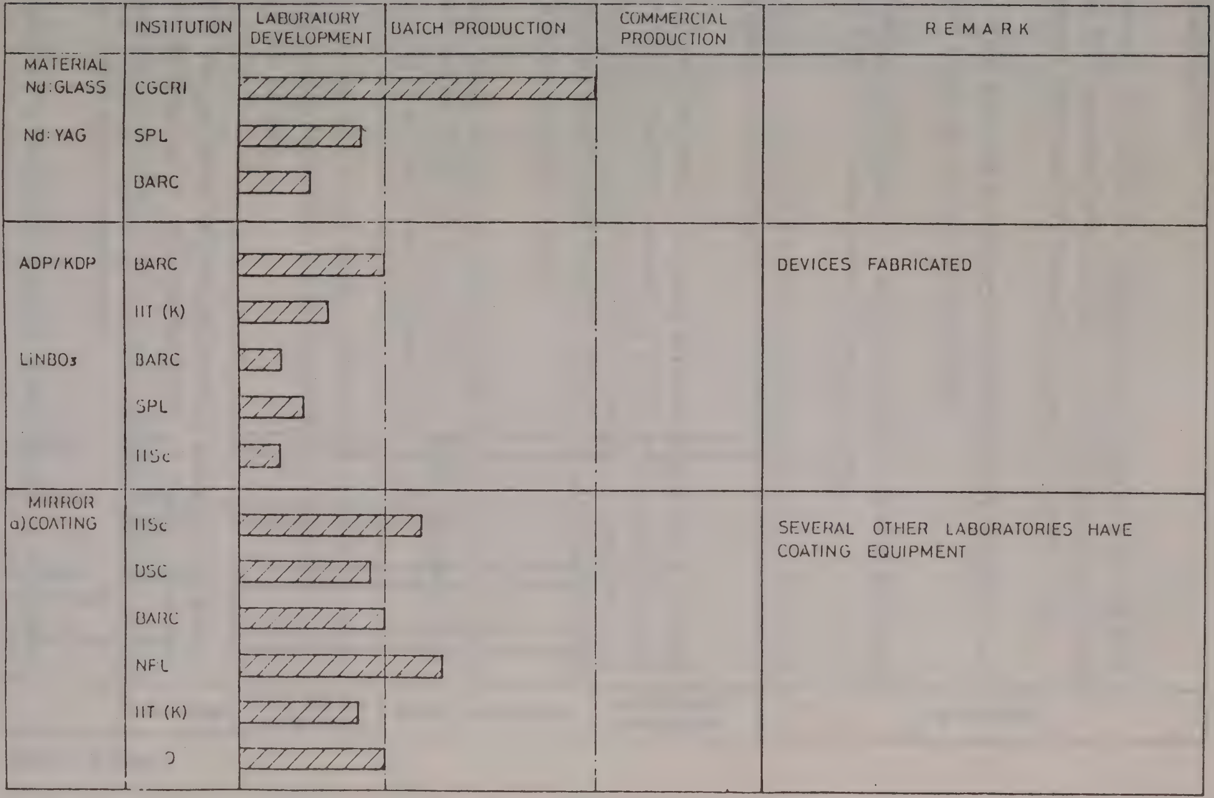
There is no work on developing laser grade gratings in India.

Energy Storage Capacitors Energy storage capacitors are required for all pulsed lasers. The specifications depend on the type of laser. For example, for ruby, Nd:YAG or Nd Glass lasers, typical values are 50 microfarad, 2.5 kv. But for the TEA CO_2 laser, the capacitor required is typically of 0.05 microfarad, 30-50 kV rating. Additionally, the capacitor should have very low inductance. The capacitors used for ruby, Nd:YAG, Nd Glass, CO_2 lasers are generally oil impregnated paper dielectric capacitors whereas those used for N_2 laser and CVL are ceramic capacitors.

Paper dielectric capacitors have been developed at BARC. With their own development, Madhav Capacitors, Poona, and Yesha, Baroda are able to manufacture and supply these capacitors. Ceramic capacitors

Table 3

The Status of Laser Component Development in India



DEVICES FABRICATED

SEVERAL OTHER LABORATORIES HAVE COATING EQUIPMENT

Table 3 (*Contd.*)

	INSTITUTION	LABORATORY DEVELOPMENT	BATCH PRODUCTION	COMMERCIAL PRODUCTION	REMARK
FLASH LAMPS	BARC	▨	▨		
CAPACITORS a) PAPER	YESHA	▨	▨		
	MADHAV CAPACITORS	▨	▨		
b) CERAMIC	BEL	▨	▨	▨	

are made by BEL.

Thyratrons Thyratrons are used with many pulsed lasers such as N_2 lasers, CVL, excimer lasers etc. There is no effort in India to develop thyratrons. Thyratrons are banned for export to India by USA.

BEL, CEL have the infrastructure to manufacture thyratrons and CEERI, Pilani can develop the technology.

Krytron is a cold cathode thyratron used for Q-switching solid state lasers. Krytrons are also banned for export to India.

Miscellaneous There are several other materials and chemicals which are required for various lasers.

Various dyes are used in dye lasers to obtain laser action at different wavelengths. Some laboratories e.g. UDCT of Bombay University and IIT, Madras are trying to synthesise these dyes and explore some new dyes for laser action. However, there is no one to supply laser dyes to users on a regular basis.

Alumina tubes and beryllia tubes are required for CVL and argon/krypton lasers. These are not available in India and there is no programme to develop them in required sizes in India.

For triggering flash lamps, trigger transformers with saturable core are used. Such core material, which can be used with microsec pulses, is not made in India.

For different gas lasers one requires various gases of high purity. These include He, Ar, N_2, CO_2, Ne, Xe, Kr, F_2, $C1_2$. Some of these are available from Indian Oxygen Co., but Ne, Xe, Kr, F_2 and $C1_2$ of the required purity have to be imported.

The status of component development in India is summarised below:

- *Components available commercially:*
  energy storage capacitors

- *Components under development and available in small number to users:*
  Nd:Glass rods, Mirror Flash lamps, ADP/KDP
- *Components under development:*
  Nd: YAG, $LiNbO_3$
- *'Critical' components not being developed in India:*
  grating, ZnSe (substrate for CO_2 laser mirrors), mirror for CO_2 laser, thyratron, krytron
- '*Not so critical' components not being developed in India:*
  ruby, laser dyes, alumina tubes, trigger transformer core, gases

4 Recommendations

The status report of laser technology in India makes it clear that India is far behind the developed countries, and even developing countries such as China, in this important area of modern technology. It may be remembered that optical spectroscopy, the very basis of lasers, was a field where Indian scientists had made major contributions which were recognised internationally. However, this background was not used to advantage in the laser R&D programmes in India which evolved later.

Indian workers in other fields, where lasers have found important applications, also failed to recognise the potential of lasers. As a result, hardly any R&D programme exists in India in some of the application areas of lasers. One can take the example of medical applications of lasers. There are only four hospitals which use lasers for general surgery. Another example is the area of laser material processing. Again there are only three laboratories in India which are carrying out some work in this field in India, Interestingly, two private sector units have recently imported laser workstations which indicates that the industry is becoming aware of the potentials of lasers.

It is thus seen that although we started our laser R&D programmes very early, today we are far behind developed countries. If this situation is to be corrected, it is necessary to strengthen our R&D programmes. These R&D programmes should cover not only the physics and technology of lasers, but also important applications of lasers in various areas.

For the R&D activity in India in the field of lasers and their applications to pick up, it is necessary to ensure the following:

- Indigenous availability of important lasers, accessories and components.
- Formulation of co-ordinated intensive programmes in a few selected areas.

To achieve these, it is recommended that

- Three laboratories should be set up or identified from existing laboratories, to take up the following programmes:

Laboratory A

- Development and limited production of important lasers (except semiconductor lasers).
- Application of lasers in medicine.
- Applications of lasers in material processing.
- Applications of lasers to spectroscopy and photochemistry and development of related instrumentation.
- Basic research in laser physics and technology, and nonlinear optics.
- Development of laser materials and components.

Laboratory B

R&D in, and limited production of,

- Semiconductor lasers.
- Semiconductor detectors.

Laboratory C

Programmes related to optical data transmission, processing and storage

- ○ Optical fibres for communications and sensor applications
- ○ Optical communication systems.
- ○ Integrated optics.
- ○ Optical information processing.
- ○ Optical computers.
- ○ Optical data storage.
- ○ Holography and its applications.

- Production units should be established with these laboratories to take up the know-how developed there.

Close co-operation with laboratories is essential to upgrade the technology with time. The production units may have to operate irrespective of economic consideration for an initial period. Rules governing import duty on components, raw material etc., should be rational. It is believed that there is an export potential for several lasers and laser based instruments. Alternatively, the laboratories should take up production for five years.

- A few academic institutions should be identified for manpower training at levels of M.Sc/M.Tech. and Ph.D.

The annual requirements of M.Sc./M.Tech. level postgraduates is expected to become about 50. The number of institutions offering such courses should be accordingly decided.

Centres should be set up at some of the academic institutions to take up research programmes in one or more areas identified for the three laboratories.

The Centre for Advanced Technology, Indore, has already proposed to undertake several of the R&D programmes suggested for Laboratory A. The proposed scope of work at CAT can be slightly expanded to include all these programmes.

The only laboratory in India with an R&D programme in semiconductor lasers is the Solid State Physics Laboratory (SPL), DRDO. However, SPL has other programmes which have a higher priority. It is necessary to substantially augment the facilities available at SPL for semiconductor laser R&D if a major programme in semiconductor laser is to be taken up there. Setting up a new laboratory for semiconductor lasers will require funds of about Rs.10-15 crores. But the semiconductor laser is such an important laser that it is worth investing this amount at this stage.

Currently, there is no single laboratory in India with major programmes in the areas identified for Laboratory C. But there is sufficient expertise in India which, although scattered over several laboratories today, will be available to form the core group of scientists for this laboratory. Funds of about Rs.10 crores will be required over a period of 5 years to take up this programme.

The following is a list of academic institutions and laboratories where centres can be established. The areas of research that can be undertaken are as follows:

IIT, Delhi	● Optical fibres, quantum optics
IIT, Kanpur	● Laser spectroscopy
IIT, Madras	● Holography
IISc, Bangalore	● Optical information processing, holography.
BHU, Varanasi	● Laser spectroscopy.
University of Hyderabad	● Quantum optics.
SCTIMST, Trivandrum	● Laser application in medicine.
AIIMS, Delhi	● Laser application in medicine.
IACS, Calcutta	● Laser photochemistry.
BARC, Bombay	● Laser spectroscopy, laser photochemistry, laser material processing.
CGCRI, Calcutta	● Laser and optical glass.

- It is also important to make users of lasers in industry, medicine etc. aware of the potential of lasers and of the availability of lasers and related equipment in India. This can be done through seminars, workshops and short courses.

Appendix-1

Properties of Lasers

Before we discuss the status of laser technology in India it will be worthwhile to mention the important properties of lasers, and some major areas of their application.

The laser is a source of light, but with an important difference. Light emitted by conventional sources is incoherent whereas the light emitted by a laser is coherent. Coherence is a measure of the correlation between light waves at different points in the light beam. If these points lie on a straight line along the direction of propagation, one is measuring correlation between light waves as seen at different times. This describes ''temporal coherence'' of the light. Temporal coherence depends on the monochromaticity of light. On the other hand, if the points lie in a plane perpendicular to the direction of propagation, one will be measuring correlation between waves separated in space, but not in time. This correlation gives ''spatial coherence'' of the light. Spatial coherence determines the propagation characteristics of the light beam.

It must be remembered that although the laser light is generally orders of magnitude more coherent than that from conventional sources, most of the lasers are not perfectly coherent. Special techniques are required to improve the coherence of the laser. It is relatively easy to get a high degree of spatial coherence of the laser beam but to achieve a high degree of temporal coherence i.e. monochromaticity is much more difficult. Fortunately, a high degree of monochromaticity is necessary only for some of the applications of lasers such as in high resolution spectroscopy, time and length standards etc.

As already mentioned, the spatial coherence determines the propagation characteristics of the beam. A laser operating in the single transverse mode emits a beam which has complete spatial coherence. Such a beam will have a divergence of only λ/d where d is the minimum diameter of the beam and λ its wavelength. Thus a He-Ne laser beam of 1 mm dia will have a beam divergence of only 0.6 m rad i.e. 2 mins of arc. However, the same laser beam if expanded to 1 meter diameter by telescope, will have a divergence of only 0.6 microradians i.e. about 0.1 sec. of arc. Such a beam after travelling 400,000 km to the moon will have a diameter of only about 250 meters. The parallelism of laser beams is utilised in applications such as alignment, distance measurement etc.

Another consequence of spatial coherence is the high brightness of the laser. The brightness is defined as the power emitted per unit area per unit solid angle by this source. The sun, a blackbody source at a temperature of 6000 K, has a brightness of about 1000 watts/cm^2/st whereas a 1 milliwatt helium-neon laser has a brightness of 300,000 watts/cm^2/st i.e. is 300 times that of the sun. The only man made light which can be seen from the moon is, therefore, a laser.

Another important consequence of spatial coherence of the laser beams is the possibility of focussing the entire beam to a spot of diameter as small as the wavelength of the laser light. It is thus possible to obtain focal spots less than 0.5 microns in diameter. This property is used in application such as optical data storage (optical video or compact discs are examples), precision fabrication of dies etc.

The intensity of laser light when focussed will obviously be very high. At moderately high intensities of about 10^6 - 10^8 watts/cm^2, which are easily obtained from many commercial lasers, the response of materials becomes nonlinear. This has opened up a new area named nonlinear optics which is of importance not only for basic research but also for many applications such as those based on harmonic generation, stimulated Raman scattering, optical bistability, optical phase conjugation etc. At these, and higher intensities, materials can be heated, melted or evaporated - processes which are used for material processing. Lasers specially built to generate very high power in short duration pulses, can, when focussed, give intensities as high as 10^{18} Watts/cm^2. Such lasers are used to produce high density high temperature plasmas - (few tens of millions of degrees) for fusion research.

As already indicated, to make lasers highly monochromatic and hence temporally highly coherent is comparatively more difficult. Commercial tunable lasers with special dispersive elements give a linewidth and short term frequency stability of about 1 MHz i.e. stability of 1 part in 500 million. Such lasers find wide applications in spectroscopy, photochemistry, photobiology etc. However, lasers used as time standards have long term stability of 1 KHz i.e 1 part in 5 x 10^{11}. Laser clocks are thus accurate to 1 sec in 20,000 years.

Lasers have another important characteristic, namely, the ability to produce short pulses of light. It is relatively easy to obtain nanosec pulses from several lasers. By mode locking, the pulse width can be reduced to a few hundred femtosec (1 femtosec $=10^{-15}$secs). This pulse can then be compressed to obtain pulses as short as 6 femtosec. Light travels a distance of only about two microns in 6 femtosec. Short pulse lasers with pulse durations of a few nanosec or picosec or femtosec are widely used for studying ultrafast processes in nature.

5

Parallel Computing

Modern applications in science and technology demand computers that are an order of magnitude faster than the fastest computer available today. Parallelism represents the most feasible avenue to achieve this kind of a breakthrough.

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Parallel Computing

Preamble

Developments in electronics, particularly in integrated circuits, have led to dramatic improvements in the capability and speed of computers, and kept their cost low. Despite this, the basic architecture of computers as proposed by Von Neumann in the 1940s has remained the same. This structure of a computer force programs to be sequential, that is, instructions are carried out serially one after another. Speed of computing can be improved by making the processors fast upto a limit. We are already reaching this limit set by fundamental constraints such as the speed of light. Speed of computing can also be increased by using many processors to cooperate in solving a problem. This second approach is now becoming very important as the reduction of the cost of individual processors has made it feasible to construct computers with a large number of processors.

The need for high speed numerical computing is felt as the number of computations to be performed in many problems is nonlinearly related to the number of data points or dimensions. For instance, the number of arithmetic operations required to multiply two (n x n) matrices is proportional to n^3. Thus, if the matrix size doubles, the number of operations will expand eight-fold. Many problems in science and engineering are solved by numerical experimentation using computer-based models. Realistic simulation requires a large number of data points. For example, to realistically simulate turbulent aerodynamic flows round aircraft wings and body, 10^7 grid points are needed. Around ten numbers are used to describe the characteristics of importance at each grid point. Around 200 arithmetic operations are to be carried out at each grid point, for each stored number, per iteration and around 200 iterations are needed for the solution to converge. Thus, the total number of arithmetic operations needed are 4×10^{12}. If each operation takes 0.1 microsecond, the time taken for one simulation is 112 hours. If the size of the aircraft increases, or if a high performance aircraft is to be designed, the computing time will increase hundred-fold to over 10,000 hours per simulation. There are many such problems in science and engineering: monsoon models, gas dynamics, molecular biophysics, quantum chemistry and reactor dynamics, to state a few.

Currently, supercomputers such as ETA, CRAY and NEC's SX2 are used to solve such problems. They typically achieve their speed by using a method analogous to an assembly line operation. An operation is broken into a set of sequential sub-operations. Each sub-operation is performed by independent hardware circuits. If a set of operand pairs are fed to the pipeline, then one result per operand pair will be available at a time interval equal to one sub-operation. For example, if a multiplication operation takes 1 microsecond and if it can be broken into 100 subtasks of (1/100) microseconds each, and 100 operand pairs are fed to the assembly pipe, one product will appear out of the assembly pipe every (1/100) microsecond. The method will work only if there are enough operand pairs to fill the pipe. The ratings such as 500 million arithmetic operations, quoted by supercomputer manufacturers, refer to peak ratings obtainable when all the pipes are filled. Average performance is found to be only about 10 to 15% of peak performance. Further, the design philosophy of supercomputers, with a primarily serial architecture, and achieving high speed by using special super speed arithmetic circuits, and the assembly line approach, is very expensive and reaching saturation.

An alternative approach currently being widely explored is to use a large number of less expensive processors working simultaneously on a task which is broken down into a large number of subtasks where each subtask can be carried out independently and at its own pace.

Each processor is quite powerful and can perform a variety of tasks. This is to be contrasted with pipeline processing in which a sequence of identical tasks are fed to a pipe. The organisation of a large number of processors which work cooperatively is called a parallel computer system. The basic challenge in designing a parallel computer system is in solving the problem of coordinating the tasks of a large number of independent computers without wasting time and effort in unnecessarily passing data and instructions among them. There are many basic questions to be answered, such as - should there be a common memory, which all processors share, or should each processor have its own independent memory or should there be a combination of both? Should every processor be able to communicate with every other processor or to only a subset of its neighbours? How should a large problem be partitioned? Should there be a large number of small tasks or a small number of larger tasks? How should these tasks be allocated to processors? All these, and many other related questions, have not yet been answered. The current challenge in computer technology is to find good answers to these questions. ■

1 Parallel Computers: Present Status

Many research groups all over the world and many computer manufacturers are developing parallel computer systems. We will look at some of the promising parallel computer systems which are useful for intensive numerical computing. The rough cost/performance of these can be seen at a glance in *Fig.1*.

We will primarily focus on the parallel computers that have already been introduced in the US market. They can be divided into six broad categories. Representative systems in each of these are discussed below.

- High speed bus oriented multi-microcomputers with cache memory systems
  - Sequent Balance 8000 and 21000
  - Encore Multimax
  - Flex/32

- Hypercube connected microcomputers
    - Intel iPSC (personal supercomputer)-message passing system
    - BBN Butterfly - shared memory system

- High performance multicomputers with high speed processors
    - Aliant FX-8
    - Convex C-1
    - Culler Scientific System
    - Floating Point System
    - Elxsi System

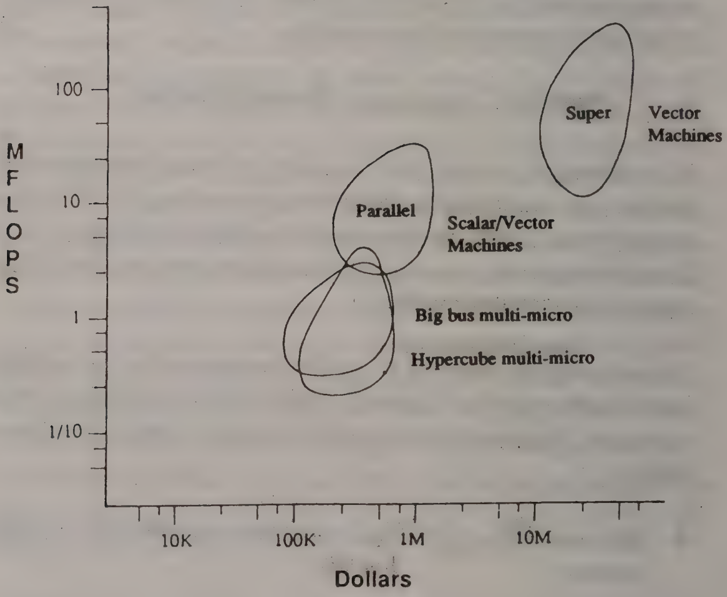


Fig. 1 Rough cost/performance ranges

- Machines with a very large number of processors
    - Connection Machine
    - NYU Ultra Computer (not commercial)

- Parallel supercomputers
    - ETA10
    - CRAY XMP-YMP
    - CEDAR (not commercial)

- Non-Von Neumann machines
    - Manchester Data Flow Computer (not commercial)
    - INMOS-based Reduction Machine (not commercial)
    - MIT - Dynamic Data Flow Machine (only simulation)
    - MIT - Static Data Flow Machine (only simulation).

1.1 High Speed Bus Oriented Multi-Microcomputers

Commercial machines, made today, connect a number of high performance microcomputers on a broad bandwidth bus. The Sequent Balance 8000 and 21000, the Encore Multimax and the Flex/32 fall in this class. The Sequent uses NS 32032 with a floating point coprocessor, an 8K RAM and an 8K cache as memory, and a custom system link chip as a communication processor, in a dual processor configuration per card (*Fig.2*). The processors are connected to a 26 MB/sec special 60 bit wide bus. This bus has multibus adapter boards and also supports memory control boards and ethernet connection besides the processor cards. Each processor works at 0.25 MFLOPS and 0.75 MIPS. The bus can support 24 processors. The peak rating is thus 18 MIPS.

The Encore uses similar processors but has a much faster bus (100 MB/sec), and has a shared memory of upto 32 MB. The bus supports upto 20 processors and the system has a peak rating of 15 MIPS. Flex also uses NS 32032 processors. For floating point processing, it uses the high speed Weitek chip. Each processor can support upto 8 MB of memory. The special bus runs at 47.5 MB/sec and can support upto 10 processors. The floating point speed of this system is high, but its MIPS rating is only around 8 MIPS (*Fig. 3*).

All the above systems, being microprocessor-based, are low cost machines - costing around US $ 200,000.

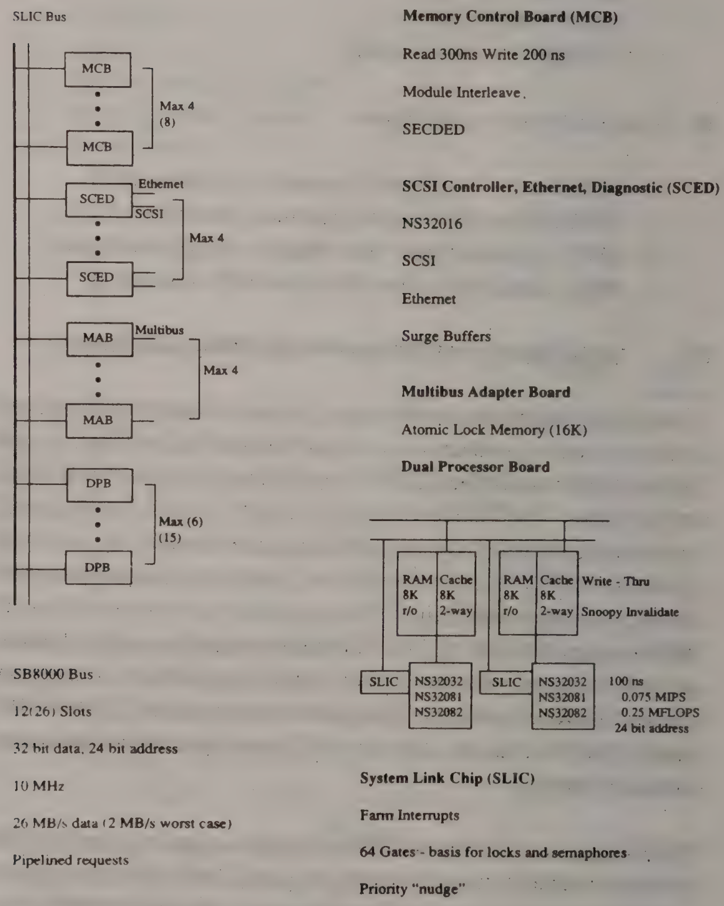


Fig. 2 Sequent Balance 8000 Balance 21000

1.2 Hypercube Connected Microcomputers

1.2a Intel's iPSC

The commercial version of the COSMIC Cube proposed by Caltech is called the iPSC hypercube. It is built and marketed by Intel Corporation.

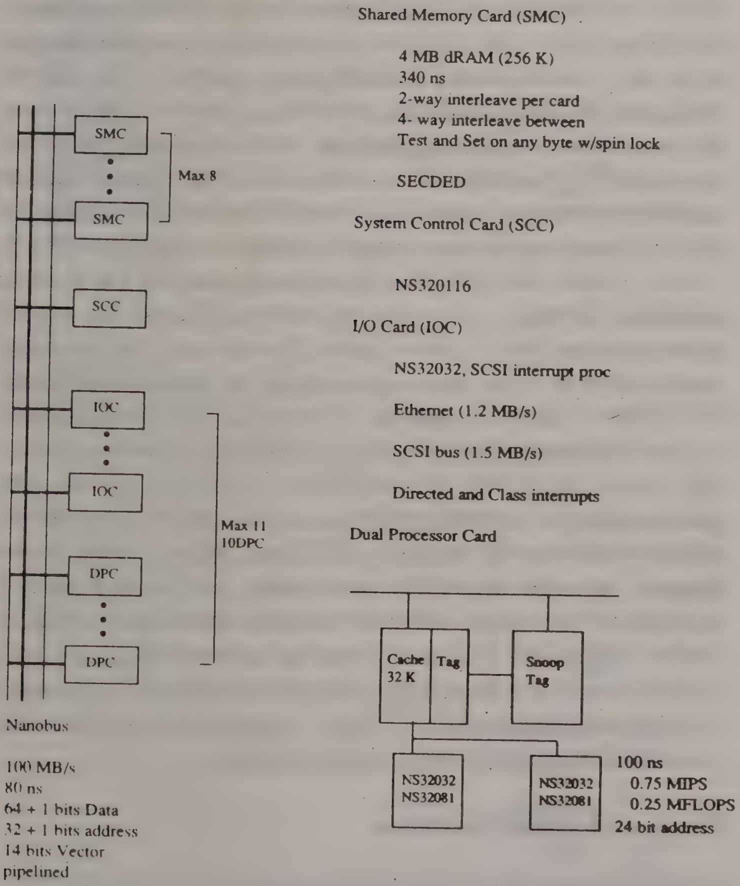


Fig. 3 Encored Multimax

The IPSC are a family of expandable concurrent computers, that use off-the-shelf VLSI components and achieve CRAY-like performance at one-tenth the price of CRAY. The performance is achieved by effective utilisation of processing resource. The hypercube architecture was developed by researchers at Caltech, who christened it the COSMIC Cube. The basic topology was evolved in 1982-83, and commercialisation was feasible within a year.

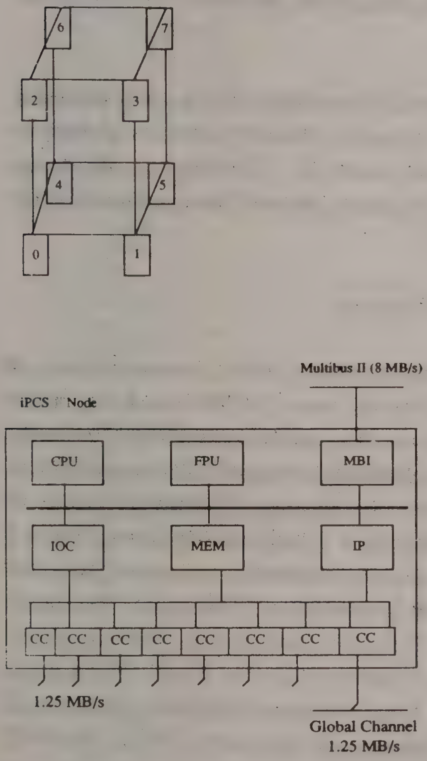
The Basic Topology and Functional Description

The binary hypercube topology is shown in *Fig. 4*. This interconnection method allows the system to be configured either as a homogeneous or a heterogeneous multiprocessor system. It can also be configured, by appropriate node addressing, as a mesh, a ring or a tree. As a mesh it has a natural organisation. As the concurrency and communication are established by sending data to the nearest Boolean neighbour, a ring interconnection is straightforward. For instance, for eight processors, addresses establishing a logical sequence of (0-2-3-7-6-4-5-1) form a ring, keeping a Boolean difference of 1 in Boolean addresses. Similarly, a tree can be realised. Clearly, the longest communication latency is bound by log 2N in all cases. The internodal communication is one hop at a time along its Boolean neighbour. Each node in current realisation allows upto seven point-to-point (nearest Boolean neighbour) channels controlled by a network coprocessor. Data is transferred between nodes as message packets. The processes spawned at nodes perform message transfer by a system call which operates on the principle of deferred polling, which allows program execution to proceed concurrently, with several pending communication requests, unless the message awaited is essential for further progression. End-to-end message acknowledge is not used unless it is built into the application layer as the bulk of the message transfers are point-to-point between neighbours, thus preventing channel hold-ups and communication overheads.

The Overall System Description

The IPSC system has two major components in its ensemble: (a) the cube manager and (b) the cube itself.

The cube manager, an Intel 80286/310 microcomputer, is linked to each node over a global ethernet communication channel. From each node (a 80286 CPU and 80287 numeric coprocessor and eight channels) point-to-point communication can be established with the seven Boolean neighbours in an ensemble of 128 processors. Each node has 512KB of dynamic RAM and 64 KB of PROM. The communication is entirely handled by the 82586 LAN coprocessor. Users interact with the system via terminals connected to the cube manager (which offers



CPU

Intel 80286
.75 MIPS
24 bit physical address

FPU

Intel 80287 (.1 MFLOPS)

MEM

512 KB (expandable to 4.5 MB)

Dual Port

Parity

Communication Controller (CC)

Intel 82586 LAN \co-proc.

I/O Control (IOC)
8251A/8254
8255A

Interrupt Processing (IP)

8259A

Cube Manager

Intel System 310

Fig. 4 Intel iPSC.

a UNIX-based programming and developmental environment).

The Operating System Services

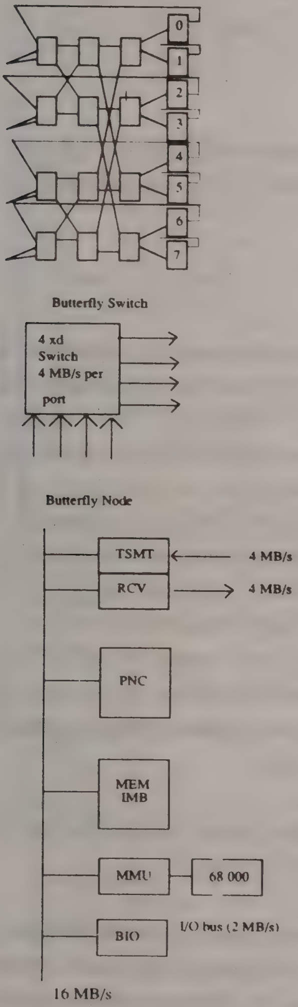
The operating system allows a user dynamic loading of programs with a view to exploit multiprocessor operation or a multiprogram operation. The message delivery system uses a transport layer protocol, and this is irrespective of whether the communication is between neighbours or not. The data message length may be of 0-16 KB, in packets of 1 KB.

The two variations that are currently available offer memory extended (MX) and vector extended (VX) series. The MX increases memory to 4-1/2 MB per processing node, while the VX uses a special vector board for vector processing. With this, the peak rating attained is 400 MFLOPS.

1.2b Butterfly Parallel Processor

The Butterfly Parallel Processor is built by BBN Laboratories Inc., of USA. It consists of upto 256 single board 68020-based computers each with 1 to 4 MB of local memory interconnected by a butterfly switch. The entire memory is globally addressed. Any processor can access either its local memory or a memory situated physically in another processor through the switch. Local memory access time is 2 microseconds, whereas access time to memory on another processor is 6 microseconds. The switch bandwidth is 32 Mbit/sec. The switch is configured using a set of 4 input-4 output units. The number of switches for a N-processor system are (N log 4N/4). The system structure is shown in *Fig. 5*. Each processor node has a microcoded coprocessor called the processor node controller (PNC). The PNC initiates all messages transmitted over the switch and processes all messages received from the switch. The PNC is also microcoded to augment 68020 to enable parallel processing. The microcoded operations include a suite of set and test operations, queueing operations, operations that implement an event mechanism, and a process scheduler, that works with the queueing and event mechanisms to provide efficient communication and synchronisation between application software modules. The PNC also uses the memory management unit to translate the virtual address used by the MC68000 into physical memory address.

Programs for the Butterfly system are written using cross-compilers



Processor Node
- MC 68000 or MC 68020 w/68881
- 1 MB Mem w/parity (4 MB expansion board)
- Processor Node Controller
- Message transmission
- test and set
- queues
- scheduling
- events

Switch Interface

I/O co-processor (2901 based)
- Multibus adapter
- Serial I/O

Fig. 5 BBN Butterfly.

and other software development tools on a front-end machine. Currently, these are written in C language and run in DEC VAX on the SUN Micro using 4.2 BSD UNIX. The Butterfly system is connected to the front end through an ethernet connection. An operating system, called Chrysalis, supports applications programs for Butterfly.

The peak rating claimed for the Butterfly system with 256 processors is 128 million instructions per second.

1.3 Aliant FX-8

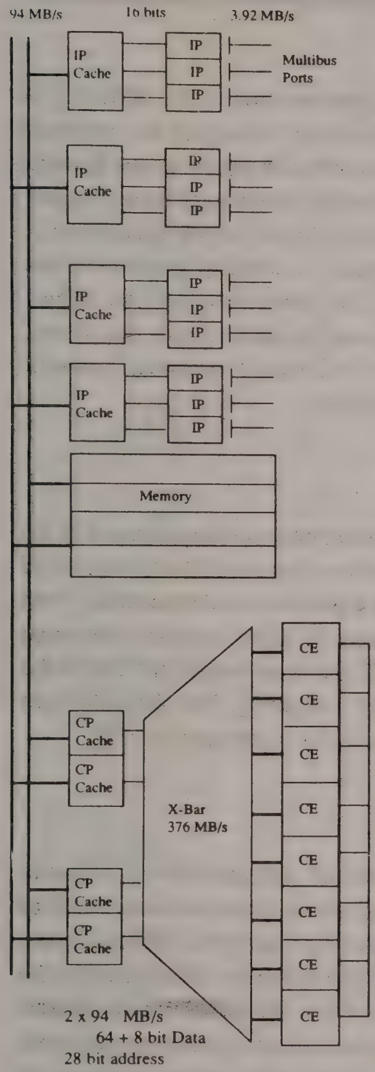
The Aliant is the University of Illinois' choice as the component computer of their supercomputer. The details of its characteristics are given in *Fig. 6*.

1.4 The Connection Machine

This machine radically departs from the other parallel computers. It was the outcome of a doctoral thesis at MIT and has since been built and marketed by Thinking Machines Corporation. This machine contains 65,536 (64K) processors, each with 4096 bits of memory and a simple arithmetic logic unit. The processors are connected in a Boolean hypercube. Each processor has 12 "nearest neighbours". Information between processors is communicated as serial binary packets and an adaptive packet switching algorithm is used. All processors execute instructions from a single stream generated by a microcontroller under the direction of a host computer (a conventional sequential computer). The machine, including the microcontroller, processor/memory cells and communication network, is packaged in a cube of roughly 1.3 m on a side.

In conventional terms, the peak arithmetic speed of the machine is 1000 million 32-bit integer additions per second.

The key component of the connection machine is a custom-designed VLSI chip that contains 16 processor cells and one router unit of the packet switch communications network. The chip has one controller, an array of 16 processors and a router. These processors are directed by the controller and perform arithmetic and logic operation on bit serial streams of data and store the results in memory.



- Interactive Processor (IP)
  - 68012 (11.76 MHz)
  - Multibus (1.96 MB/s)
- IP Cache
  - 32 KB of 85 ns stauc RAM
  - 32 B block
  - Conherence by software
- Global Memory
  - 64 MB in 8 MB modules
  - 340 ns dynamic RAM (256 kb)
  - 4-way interleave
  - (188 MB/s sequential read)
  - (150 MB/s sequential write)
- Computing Element (CE)
  - 68020 architecture (32 bit) in CMOS gate-array and TTL
  - Multiple Functional Units
  - Vector Registers (8 x 32 Word)
  - Concurrency Control
  - 16 KB Instruction Cache
  - Scalar 4.45/3.63 MIPS (32/64)
  - Vector : 11.85/5.9 MFLOPS(32/64)
- CCP Cache
  - 4 x 32 KB
  - 85 ns static RAM
  - pipelined operation (3 requests)
- Concurrency Control Bus

Fig. 6 Alliant FX-8.

The communication network of the connection machine is formed by 24576 bidirectional wires. The routers are wired in the pattern of a Boolean 12-cube. The router buffers and forwards information to and from processing cells.

The main drawback of the connection machine is the difficulty in programming it. Even though the machine is designed as a multiple instruction multiple data stream computer, loading programs through a very narrow communication path in the computer is time-consuming. Further, collating the input/output from 64,000 processors is slow compared to the processing speeds. As of now, it seems that this machine will work effectively only for problems which can be programmed using single instruction multiple data stream algorithms. Typical problems of this type are in image processing, quantum chromodynamics and pattern recognition.

1.5 The CEDAR Computer

CEDAR is the parallel supercomputing project being pursued at the Centre for Supercomputer Research Development at the University of Illinois. The primary objective of the project is to demonstrate ''that parallel processing can deliver good performance across a wide range of applications''. To that extent CEDAR is an important effort in the direction of general purpose parallel computing. The plan is to have a prototype ready by 1990. The project was initiated in 1985.

The CEDAR Architecture

Functionally, CEDAR has a three-tier arrangement as shown in *Fig. 7.* Even though CEDAR has adapted a shared memory model of computation, the locality of references is attempted within a cluster. The idea is to split a given problem into sub-tasks which generate the locality of references within clusters that can communicate at ultra-high speeds. Currently, eight processor clusters have been employed. The algorithm is split to ensure a very high cluster residency as compared to the requirement of inter-cluster communication. This ensures that the synchronisation penalties are very low. At the innermost level each of the processors in the cluster has vector capabilities

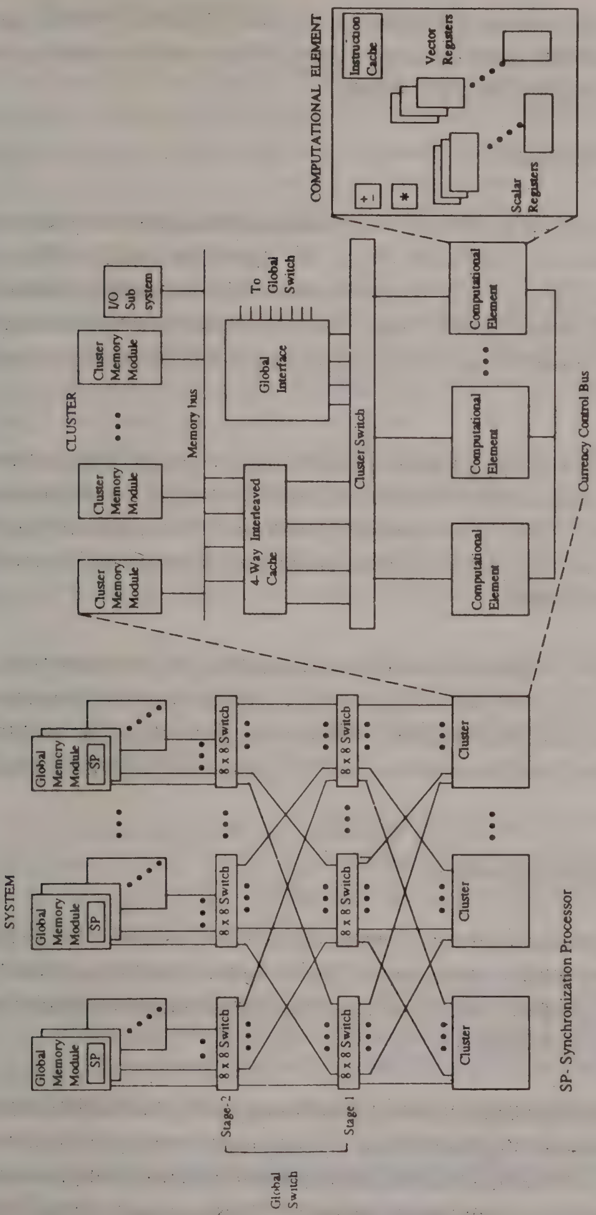


Fig. 7 Cedar system organisation.

offering it a raw parallelisation at the hardware level. The designers believe that the three-tier approach will offer a uniform speed-up over a wide spectrum of applications.

Structural Details

Each cluster is an Aliant FX-8 minisupercomputer in which eight processors are connected by a full cross-bar switch. The eight processors also share a four-port cache. Each computing element has a Weitek floating point chipset with two multipliers/dividers and an adder/subtractor logic offering operation at 6 MFLOPS (peak) on 64 bit words.

The shared memory modules communicate with the cluster through an interconnection network framed by cascading 8 x 8 switch arrays. The switch offers a full crossbar performance. It is precisely for this reason that the synchronisation penalties are substantially lower in the CEDAR system.

The cluster memory modules are supported on a memory bus and intra-cluster communication is via a cluster switch between the processor and the four-way interleaved cache with high locality of reference. Each processor has a UNIX system environment to regulate traffic.

Reported Performance

The reported performance on one cluster of the system is 20 MFLOPS for dense matrix computation. This is within 10 to 20% of CRAY 1-S. For a properly restructured case, the performance may well range upto 50% of CRAY 1.

An important aspect of the CEDAR approach is the emphasis on re-structuring of a given problem. The attempt is to map the problem to make it effectively use the organisation of the cluster of processors. We would like to emphasise that the CEDAR approach clearly brings out a need for the development of parallel algorithms and tools to map these on parallel structures.

2 Recommendations

It is evident that the design of parallel computers is a nascent technology, and that this is the right time to enter it. Many development projects such as oil exploration, monsoon modelling, molecular models of plant viruses, processing satellite images, etc. need numeric intensive computing at very high speeds which can be achieved using parallel computer systems. A major challenge in parallel computing is the development of algorithms and software to optimally utilise these systems. Such software will be a multibillion dollar business in the next decade. It is difficult to optimally transform existing software working on single processor sequential machines to programs on emerging parallel machines. As we have not so far invested large funds in serial programming, it would be worthwhile to discover novel parallel algorithms in diverse fields of science and engineering to exploit these emerging systems. It is thus the right time to initiate research and development work in a parallel computer system. The major objectives of such a mission should be:

- To build a parallel computing system, with associated software systems, to solve numerically intensive problems in science and engineering. The parallel machine should have a minimum sustained rating of 50 MFLOPS.

- To create groups of research scientists and engineers who would develop new parallel computing algorithms, and applications software, in their specialities, to effectively utilise parallel computers to attain their potential performance.

- To create a group of software scientists who would tackle the problem of restructuring and transforming existing large applications programs in a semi-automatic way so that they could be executed on parallel machines.

In order to meet the above objectives, the following actions have to be initiated:

- Create an organisation which will have the responsibility to design and build a parallel computer of appropriate architecture. This should be a manufacturable prototype. All the associated software, such as the operating system and high level languages, should be designed and installed on the prototype model.

- The organisation should have operational autonomy and must be structured to enable speedy execution of its goals.

- The organisation should have close interaction with a computer manufacturing company and with research groups in other organisations to whom appropriate tasks should be allocated. For ease of coordination, all these organisations should be connected together by a computer network and video conferencing facilities.

- To meet the second objective, it is essential to identify application areas in science and engineering which are numeric intensive, and research groups which are active in these areas. Each of these groups must be given a parallel computer, of an architecture similar to the one which will be locally designed, with a specified goal of creating algorithms and programs in their specified area appropriate for this parallel architecture. The implemented programs should be portable to the machine to be designed.

- A group should be formed by the organisation with the goal of restructuring sequential programs to run on the parallel machine. This group will work intimately with system architects and language designers of the parallel computer and have the restructuring tool ready at the time that the machine is ready.

2.1 Main Mission Activities

A list of the main activities to be carried out, and their time requirement, is shown in Table 1. The corresponding timing chart is also given (*Fig. 8*).

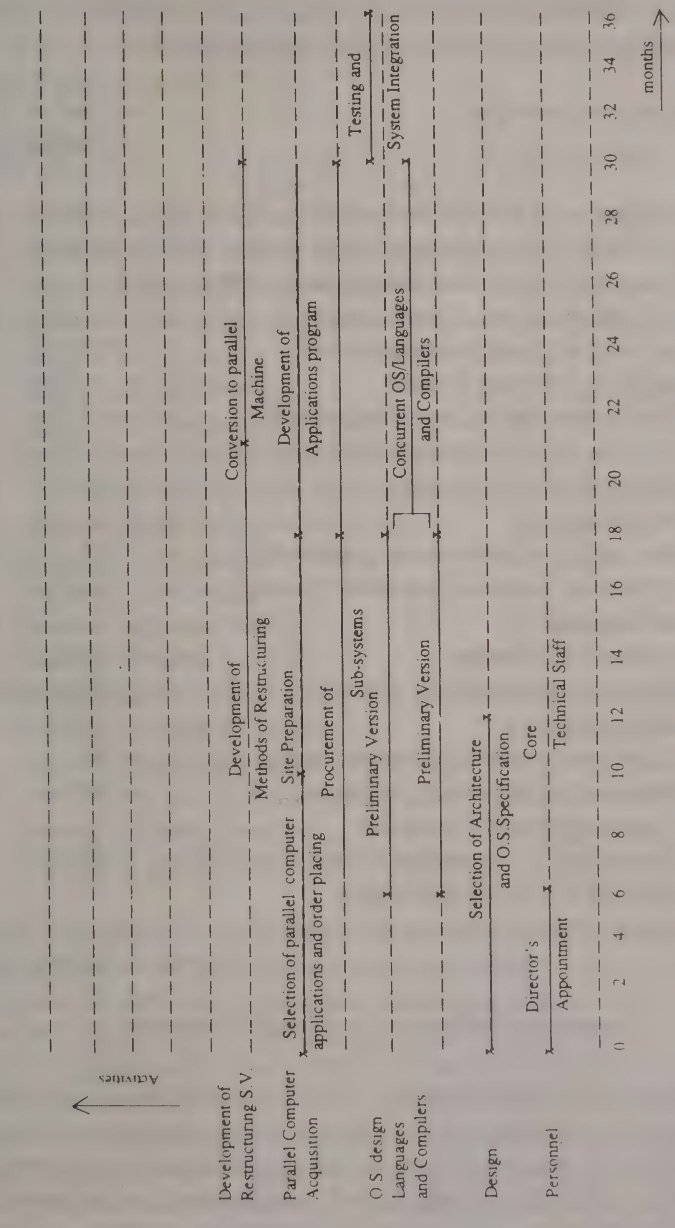


Fig. 8 Timing Chart Showing Activities and Overlaps.

Table 1

The Main Activities of the Parallel Computing Mission

Detailed set of activities	Time in months
● Acceptance of mission; budgets and appointment of Executive Director of the Centre for Parallel Computer Development	Start of project
● Recruitment of core technical staff	6
● Decision on parallel computers to be bought and placing of order	10
● Architectural design, operating system and language specification finalisation	12
● Arrival of parallel computers and distribution	18
● Procurement of subsystems, components	18
● Preliminary version of operating system and language	18
● Computer fabrication	30
● Final design of operating system and languages	30
● Delivery of parallel application programs	30
● Restructuring sequential programs to proposed parallel computer	30
● System testing, implementation of operating system and languages, system integration with applications	36

2.2 Application Software for Parallel Computers

As pointed out in the earlier part of this report, it is not sufficient to design a parallel computer hardware and the requisite operating systems and languages. The greater challenge is in developing efficient application programs which can effectively use the power provided by the parallel computer. Application programs can be developed only by engineers and scientists who are active users of

Table 2

Subjects Requiring Intensive Computation, and Organisations Competent in these Areas

Subject	Organisation
● Fluid dynamics, turbulent flows	NAL, Bangalore
● Monsoon models, weather prediction	IMD, Delhi
● Structural analysis of large structures	IIT, Kanpur
● Combinatorial optimisation techniques, LP, NLP, ILP, etc.	IIT, Kharagpur
● Geological exploration	ONGC, Dehra Dun
● Structural and quantum chemistry, molecular biophysics and genetics	IISc, Bangalore
● Physics (theoretical, solid state, etc.)	TIFR, Bombay
● Reactor design, heat flow problems	IIT, Bombay
● Computational geometry, vision and image processing	IIT, Delhi
● General purpose simulation of complex dynamic systems	IIT, Madras
● Processing of satellite images	NRSA, Hyderabad
● Satellite tracking, guidance systems, aerospace structures	ISRO, Bangalore
● Atmospheric and plasma physics	PRL, Ahmedabad
● General purpose numerical algorithms, graphics and CAD	NCST, Bombay

computers, and who need the potential power of parallel computers. The application software area in parallel computing is in its infancy and has the potential to become a multibillion dollar worldwide industry. It is thus essential to identify premier organisations in India, specify application software systems to be developed by each of these, invite proposals and fund them by providing them with a parallel computer and the necessary budget. Each organisation will have a time target to provide the requisite application systems. A tentative list of subjects, in which numerically intensive computations are to be carried out, and organisations with competence in these areas is shown in Table 2.

Once an appropriate parallel computer architecture is identified for design and manufacture, similar commercial computers should be ordered and distributed to these organisations so that they can concurrently begin application software development. If the activity is properly planned, when a parallel computer manufactured in India gets ready, the application software for it in a large number of important subjects would also be ready.

2.3 Staffing and Budget

The project should have, besides the Project Director, three Associate Directors to look after hardware, system software and application software, 36 design engineers and 12 non-technical staff. The Director must have autonomy in day-to-day working, sub-contracting jobs, appointing consultants, etc. A structure similar to C-DOT would be appropriate.

The total budget break-up of the project (based on a detailed analysis) could be as follows:

● Cost of local equipment and components	Rs 710 lakhs
● Cost of imported equipment and components	US $14.25 millions
● Maintenance, salary and contingencies for three years	Rs 575 lakhs

3 Summary

With the advent of inexpensive and powerful microprocessors, it has now become feasible to build a computer by interconnecting a large number of microprocessors. Such a computer, called a parallel computer, can be designed to solve problems requiring numerically intensive computing. There are a large number of applications, critical to India's development, which require sustained numerical speeds in the range of 10 to 100 million arithmetic operations per second. It is thus necessary to initiate a technology mission with a goal of building such parallel computers by 1990. The potential hardware speed of parallel computers cannot be utilised unless new algorithms tuned to the parallel structure of these computers are developed. Research in parallel algorithms is at its infancy and a major effort can potentially give us the leadership position in this area. It is thus proposed that commercially available parallel computers be distributed to fourteen organisations and individual goals be defined for each organisation to develop parallel programs in their area of competence. These programs should be implemented on the prototype parallel computer developed by the mission.

It is proposed that the mission be coordinated and executed with a separate identity and autonomy of operation. The proposed budget for the mission is Rs. 32.0 crores of which US $ 14.25 million will be in foreign exchange.

[illegible]

[illegible] must have capacity [illegible] consisting [illegible]

[illegible]

Summary

[illegible] Such a [illegible]

[illegible] can be designed to solve [illegible]

[illegible]

6

Instrumentation

Instruments represent the cornerstone of both science and technology. It is difficult to see how we can be strong in science and technology if we do not have our own base in this critical area.

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6

Instrumentation

Preamble

Instruments can either be of the stand-alone type or be part of a larger system. Either way, instruments find use in a wide variety of fields - education, R&D, industry, defence, environment, medicine, agriculture etc. Originally an instrument implied a measuring instrument but in this report we shall use the term in a generic sense to also include systems like the laser.

Recognising the importance of instrumentation, several committees have been appointed in the past to make recommendations for improving the status of the instrumentation industry in the country but, unfortunately, there have been slippages in the implementation.

At this juncture, there is (a) an increased emphasis on the power, oil and industry sectors, (b) an increased concern about the environment, (c) an anxiety to revamp education, (d) a keen desire to get a start in biotechnology, (e) above all, a hitherto nonexistent commitment to high technology. Under the circumstances, the rapid expansion of our instrumentation industry becomes an urgent necessity. It is almost a now-or-never situation, and, for this reason, it is hoped that the present set of recommendations will not receive the same fate as the earlier ones.

The following Sections summarise the present status of the field and present recommendations.

1 Current Status of Instrumentation in India

The current scene can be paraphrased in one word - patchy! As far as the industrial sector is concerned, practically everything is imported, lock, stock and barrel. In the defence sector, many systems are designed and assembled in India but they depend substantially on imported components. Where experimental science is concerned, the bulk of the instruments needed are currently being imported. With the advent of the OGL, the availability of customs duty exemption for R&D etc., import has become fairly widespread. Interestingly, inspite of this, some of the major R&D groups in the country have spent much effort to build their own instrumentation. The optical telescope at Kavalur and the radio telescopes at Ooty and Bangalore provide major examples. In a special issue of the *Indian Journal of Pure and Applied Physics*, (July-August 1989 issue) the spotlight is on the instrumentations scene in India, with many articles on instruments designed and built here. Notwithstanding all this, the real problem has been that R&D has not made an impact on our industry. This is neither the fault of R&D nor of the industry. The fault lies in our value system and our priorities.

In a nutshell, we are, at present, heavily dependent on imports. The only way to get out of this rut is to first massively encourage the system engineering of instruments, with perhaps imported components. In the next stage one should start making the critical components also, perhaps with imported materials. In the final stage we should make our own materials.

The argument is made that our quantities are small, that we should not try to make everything here etc. This ignores the fact that when quantitites are small, many sellers abroad are not willing to sell because we are so far away. And even when they sell, the after-sales service tends to be quite poor.

Instruments represent the cornerstone of both science and technology. It is difficult to see how we can be strong in science and technology if we do not have our own base in this critical area. For years we have done precious little to close the gap between us and the advanced countries. Meanwhile, the gap is widening to worrisome, if not awesome, proportions. It is almost a now-or-never situation.

2 Recommendations

A short-term as well as a long-term strategy is desirable.

- On a short term, it is recommended that a crash programme be launched immediately to manufacture a dozen or so badly-needed instruments catering to different sectors. Such an effort would not only have the merit of servicing unsatisfied (and in some cases long-standing) demands, but can also serve as a visible proof of the new thrust and the new strategy. Further details are given in Section 2.1.

The long term strategy is directed towards the creation of a chain of hitech industries which will produce various items, ranging from components to subsystems, which are needed in sophisticated instruments. This necessarily involves anevolutionary process which is outlined in Section 2.2. At least ten years from now, the country must have a sound base for indigenously meeting the needs of our strategies sectors. Given below are several recommendations pertaining to the long-term strategy.

- Building modern instruments often requires high technology. In turn, hitech requires, and also advances with, the help of sophisticated instruments. Government must therefore declare instrumentation as a crucial area of development and extend appropriate special treatment as has been done recently in the case of electronics. Further details are given in Section 2.3.

- For the instrumentation industry (and therefore, by implication, also for hitech) to grow, one needs a chain of industries making subsystems, components etc. It is clearly neither possible nor desirable for Government to start and run such an interlinked chain of industries. Instead, Government must reverse its present policy and throw hitech open to the entire industry - both public and private.

- Hitech instruments and subsystems, needed for defence, are, at present, either produced by the Government defence production units or imported, and there has been a reluctance in the past to discuss defence requirements with our private sector. This attitude needs to be overhauled for a number of obviously good reasons.

- Industry - both public and private, thrives only if it can make profit. In the past, instrument manufacture was not a profitable venture. But it can be made so, provided there is a bold and imaginative fiscal policy. We urge such a policy, and spell out its details in Section 2.4.

- Government has as crucial role to play, starting with high-level policy making right down to the routine, operational level. A separate section is therefore devoted to this subject. In brief we recommend that Government must (a) play generally a promotional rather than a strict regulatory role, (b) create and operate a special R&D fund (c) organise and operate an appropriate data bank, (d) create an agency or agencies which will provide procurement/marketing assistance, especially to industries in the small-sector, (e) establish a mechanism for continually monitoring the implementation of the thrust strategy proposed here, and make mid-course corrections as required, (f) establish a special Directorate for dealing with the above tasks, as also for monitoring R&D, overseeing the linkage of R&D with industry, the unpacking, assimilation and updating of imported technology packages, etc.

- We urge that R&D on instrumentation in the national laboratories, IITs etc. be stepped up. Specific recommendations in this regard are made in Section 2.5. We also recommend joint R & D involving industry and the national laboratories, especially on mission-oriented tasks. The time has also come for our industry to take R&D more seriously, like its counterpart in the more advanced countries.

- Notwithstanding certain failures in the past, 100% export-oriented instrument industries are possible, provided the mistakes of the past are suitably corrected. While the produce of such industries might not make an impact on the Indian scene, there would be many indirect fallouts. The creation of such industries therefore seems worthwhile.

- A considerable amount of equipment already purchased (both locally and by import) lies unutilised due to breakdowns caused by inadequate maintenance. Any leap-frog programme in instrumentation must therefore give due attention to maintenance. We recommend (a) a suitable training policy, (b) a spares procurement policy in respect of imported equipment and (c) an appropriate after-sales servicing scheme in respect of instruments made in India.

- Instruments play an important role in science education and we can no longer afford to neglect them as in the past. Our recommendations are detailed in Section 2.6.

- If there is to be a take off in instrumentation, then a concomitant planning of human resources is also needed. Suggestions concerning this aspect are made in Section 2.7. This Section is also the repository of various other comments which do not fit elsewhere.

2.1 Crash Programme to Achieve Immediate Impact

- Nothing succeeds like success. Remembering this, our first recommendation is to launch a crash programme for the manufacture of a dozen or so instruments. A brief description of the list selected by us along with a few other relevant particulars are given in Table 1.

There is nothing sacrosanct about our list. Other equally good lists can be drawn up. The important thing is to have a target and then get a move on. However, we do believe that the items selected by us are needed widely and therefore merit attention.

- While recommending our own list, we would like to add that the DST has already launched a programme of R&D on several, much-needed instruments. Our recommendations are without prejudice to existing efforts. Indeed, those DST-sponsored projects which have reached a state of fruition can be considered for inclusion in the crash programme suggested here.

Table 1

Suggested List of Instruments for Indigenous Manufacture

Instrument	User Community	Remarks
Opthalmoscope	Doctors and medical students	Large numbers needed. Does not involve sophisticated technology.
Multichannel data acquisition system	Hospitals, industry etc.	A simple version linked to an PC appears to have a wide-spread use and therefore market.
Infrared distance measuring equipment	Defence, civil engineers	At present about 800 systems are being imported every year, at a cost of Rs 10,000-20,000/system, depending on the sophistication.
X-ray based instruments like diffractometers etc.	R&D, analytical laboratories	There is a considerable amount of know-how available. But it is not in a finished form as a technology package.
Image analyser	R&D, some industries	The technology is not ultra-sophisticated, and appears quite accessible provided some effort is made. About 50 units are imported every year, costing Rs 1.5 lakhs each.
Scanning electron microscope	Education, R&D industry	The existing DST-sponsored project should be used as the base to launch production.

Table 1 (*Contd.*)

Instrument	User Community	Remarks
Leak detector	R&D, industry	CAT, Indore/BARC, Bombay have working prototypes. They could be considered for generating the required technology package.
UHV subsystems and analytical instruments based on UHV	R&D, defence research, semiconductor industry	Some knowhow exists in the country but is scattered at present. However, the subsystems industry can be manufactured in the country, and they are ideal for the small scale sector. UHV instrumentation manufacture is an ideal test bed for trying out the industrial coop idea discussed later.
Auto exhaust monitors (portable)	Environment inspectors	There will clearly be an increasing demand for pollution monitoring equipment. This is the simplest to start with. The product line could be expanded later.
Argon-ion laser	R&D, medical community	Even groups with considerable experience in lasers are avoiding the development of this instrument! But it is very important and therefore a thrust is necessary.

* In all cases, except perhaps the argon-ion laser, there are no major knowledge or technology gaps. Therefore, a time-bound programme is possible. Indeed it is a *must*. Given the rapid obsolescence in the instrumentation industry, it does not make much sense if products selected now appear five years later on the market!

- Mechanics of implementation
  - We recommend the creation of a special production agency, with considerable flexibility and autonomy (possibly on the lines of C-DOT).
  - The structure of the proposed Agency is indicated in *Fig. 1*. Attention is drawn to shops supporting some of the ingredient technologies. In the long run, some of these may be necessary for producing the key components.
  - To start with, the Agency could concentrate on system engineering i.e. operate on loop 2/3 of *Fig. 2*.

(Roughly modelled after Cambridge Instruments Ltd.)

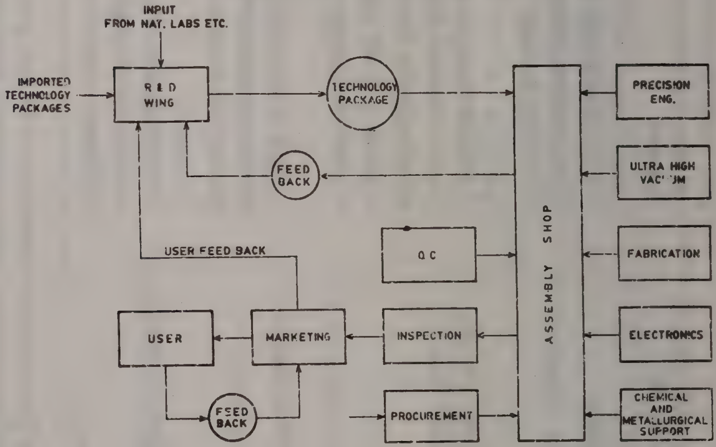


Fig. 1 The structure of the proposed special production agency for instrumentation.

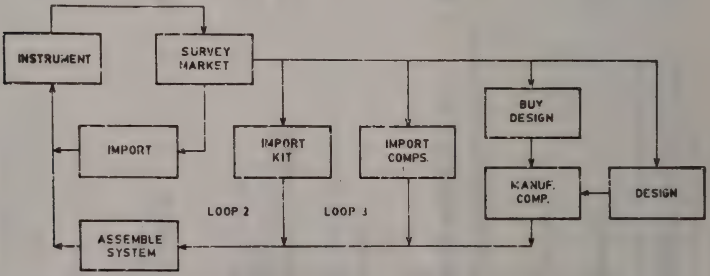


Fig. 2 Schematic of the various loops of the production cycle.

- For convenience, there could be separate wings to cater to the instrumentation requirements of the various sectors. However, there must be complete standarisation across the board.
- The Agency must be supported by an active front end which selects technology packages which must be imported, unpacks packages so obtained and finally assimilates indigenous R&D and adapts it for production.

- *Funding* We are unable to indicate at present the kind of funding needed to start the proposed venture as there was neither sufficient time nor data to carry out the exercise. However, if one starts with system assembly, initial investment may not have to be high. But progressively more investments would be called for as the activity moves to the outer loops of Fig. 2.

- *Market assurance* Without a market, industry will languish even if there is price support. Due to a paucity of detailed information, we are unable to project a market in respect of certain instruments like the argon ion laser. However, guided by our own individual knowledge of the present quantum of import, we feel that there is enough of a potential market at least at the level of initial production. In some cases, like opthalmoscope, the market can be predicted with greater accuracy.

It is important to ensure that the Agency we have recommended is given a sufficient guarantee that its output would be lifted. Ultimately, the Government pays for most of the instruments bought. Keeping this in mind, the various Departments of the Government must make firm and advance commitments for purchase. This is not an unreasonable expection. Government has already done this in the case of C-DOT. One expects the UGC, the Ministry of Health, the Department of Environment etc. to follow suit in the present case. Equally, the Government may have to be firm in curbing the import of models comparable to those available indigenously. It is of course assumed that the local products would be manufactured to the desired level of quality and reliability.

- *Price support* It is not enough to give just market assurance. In fact this may not be possible unless there is also price support. Essentially, all raw materials, sub-systems, components and design must be available at international prices. In addition, the capital equipment needed for manufacture must also be available at international prices.

- *R&D* The production strategy we have recommended requires a strong R&D in instrumentation, and is sufficiently important to warrant separate discussion (see section 2.5). Here we note the following: Each of the selected instruments of the 'crash programme' must be factored into subsystems/components. The next step should be to see which of these can be made locally and which need to be imported. Specifications must then be laid down for all the subsystems. There is now the problem of generating designs for subsystems to be made locally. This task must be handled by laboratories with expertise in the area concerned. It is likely that the laboratories may be reluctant to undertake the assignment. However, if there is a directive, and a priority assignment by the highest authority, the reluctance may well be replaced by a sense of mission. In every case, there must be peer committees to monitor the entire process, starting from the laying down of specifications to the testing of the prototype.

The R&D cell of the proposed Agency could initially function on an academic campus such as that of the Indian Institute of Science (this would facilitate drawing upon the diverse expertise available in the campus). The Indian Institute of Science appears to be a good choice also because it has a Central Instrumentation Laboratory on the campus. Eventually it could move over and be integrated with the manufacturing wing.

The job of the R&D cell would be to do system design in collaboration with the identified agency. The cell must ensure that a technology package (as defined in Section 2.5) results finally. The campus location would facilitate day-to-day consultancy with specialists, as also access to computing facilities.

- *Ancillaries* The proposed Agency must function as a catalyst for the growth of small scale industries which can supply components and subsystems.

Clearly much detailing needs to be done with respect to the above ideas. But this task can wait till the Government gives its approval to the proposals.

- Also recommended are a few futuristic projects like
    - ○ Monitored and controlled infustion systems (needed in hospitals)
    - ○ Diagnostic instruments based on magnetic fields produced by the human body (This may involve SQUIDS and is a very exciting and challenging goal)
    - ○ Infrared, portable toxic gas leak detectors.

2.2 Broad Strategy

The growth of our instrumentation industry has tended to follow a well-established pattern schematised in Fig. 2. Essentially, the market, for a particular product, is first located and then serviced by import. The next step is manufacture based on imported kits or subsystems. Eventually, everything is indigenised, including the design. There are many loops, and different products are on different loops. Most of the sophisticated instruments are still on the innermost loop i.e. that of total import. On the other hand, low-bandwidth oscilloscopes are today substantially Indian is origin.

There is a similar looped structure with respect to technology packages and, as is to be expected, there is an organic relationship between the two looped structures.

In the case of the electronics industry, thanks to drastic changes in Government policy, there has been a remarkable spurt, with more and more products moving to the outer loops. It is recommended that a somewhat similar strategy be followed in respect of instrumentation. Specifically:

- It is necessary to provide a new pathway for growth via the formulation of dynamic, growth-oriented policies, and

- It is equally necessary to devise a steering mechanism so that growth follows the track that has been laid out instead of erratically going elsewhere.

The rest of this document in an attempt to spell out some of the modalities of achieving the broad strategy outlined above.

2.3 Incentive to Industry

This is an important section. Our instrumentation industry has not done well, and there are a number of reasons for the poor record thus far.

Among the many factors inhibiting the growth of the instrumentation industry are:

- non-availability of raw materials and components at international prices.
- the very heavy import duty on components and raw materials required to be imported.
- lack of a national policy on instrumentation development.

All this must change. Government has already recognised instrumentation to be a key industry. As a logical follow up, Government must extend all the support a key industry deserves. It should not curb enterprise by bureaucratic red tape and inhibitory policies. Rather, Government must treat the instrumentation industry like it has recently begun to treat the electronics industry. Some specific suggestions in this regard follow:

2.3a R&D Cess

Parliament has recently passed a bill by which a 5% cess will be levied on all payments for purchase of foreign technology and royalty payments. As this sum is a levy on imported technology, it is presumed that the funds collected would be available for developing a sound base of the indigenous technology. We have discussed elsewhere how such a fund may be operated and used for promoting R&D. Here we observe:

- The levy should be made payable only by companies that make profits as computed under the Income Tax Act, 1961 under the head ''Profit on Business''.

- The levy could also be as a percentage of the value added by the industry and not on the turnover. This is needed to protect the legitimate interests of industries that have large turnovers but with small value addition.

- Industries already spending 2% of the value added, could be considered for exemption.

- Industries having in-house R&D expenditure in excess of 1% of the value added could be exempted from the levy.

2.3b Customs

- Progressive decrease in customs duty from finished instruments to raw materials under a 3-tier system, i.e.
    - Complete instruments
    - Intermediates
    - Components and raw materials.

- If raw materials and components are not available basically, and there is no indigenous industry protection angle involved, the custom duty should be zero.

- Customs Duty on components and raw materials should be the same irrespective of their end-use.

- Instruments are mostly covered under chapter 90 under the Customs Tariff Act, 1975, and would enjoy the reduced customs Duty. There are some instruments/items covered under chapters 84 and 85 which would not enjoy this benefit. unless they are separately grouped and specified as such in these sections for favour of enjoying the revised customs duty. This should be done.

- *Designs and drawings* At present designs and drawings are subject to customs duty at 30%. In order to encourage indigenous development of the Instrumentation Industry, this duty should be totally withdrawn.

- *Capital Goods Licence* Concessional rate of duty for Instrumentation Industry: DGTD/Department of Industrial Development should be authorised to recommended concessional rate of Customs Duty for the Instrumentation Industry along lines similar to those already done for the Electronics Industry.

- *Import of Raw Materials and Components* Concessional rate of Duty: DGTD should be authorised to recommend a concessional rate of customs duty on raw materials and components, for the Instrumentation Industry also.

Similarly, in the case of small scale units, DCSSI should be authorised to recommend the grant of concessional customs duty both for CG licences as well as for raw materials and components. This is necessary to enable the instrumentation industry to be competitive in its product prices for export and in tenders against World Bank loans.

The recommendations of DGTD, etc., should be made binding on the customs authorities and the latter should not insist on payment of customs duty first, and making the refund claim subsequently, as this is an unnecessary blocking of capital and causes avoidable hardship to the industry.

In order to develop the domestic manufacturing capabilities, it is suggested that all imports of instruments, and components thereof, by the unorganised sector should also be covered by the list attestation procedures and the phased manufacturing programme, as in the case of the organised sector.

- *Customs Duty on samples* The duty on samples being obtained for reverse engineering or study of competitive products should not be more than the duty charges of the capital goods.

- Imports for registered R&D units (with Department of Science and Technology) should be completely exempted from Customs Duty.

- *CVD on Re-import* Goods sent for display in exhibition/trade fairs outside India are subject to countervailing duty when re-imported. No CVD, equivalent to excise duty, should be charged on reimportation, as these are products of the same company coming back and no fresh manufacture or sale is included.

2.3c Excise

- Prototype instruments to be exempted from excise duty. These are generally sent out for field trials for obtaining users' comments for incorporation in the final design.

- Instruments sent for demonstration and evaluation, should be allowed to be cleared free of excise duty subject to the execution of bond.

- *Repairs* Under the Central Excise Rules, it is necessary that, whenever instruments are received in the factory for repairs, the excise authorities be notified, and that a time limit of 30 days be allowed to complete the repair and return the instrument. Since in most of the cases it is not possible to undertake the repair within such a short period, it is suggested that the time limit should be restored to 120 days, as was the case earlier, and a simplified procedure prescribed for the return of the good after repair without GP-I, and without payment of excise duty, if the repair is undertaken within the warranty period. Duty should be payable only in cases other than above, and on the amount charged for repairs.

- *Supplies to Hospitals. Educational Institutions and Registered*

R&D Units The excise duty should be completely waived. Since there is no customs duty on imported equipment for these institutions, there is no rationale in charging excise duty on such supplies. Further, some of the states are not even charging sales tax for supplies made to hospitals and educational institutions. The total excise revenue earnings from the entire country on sale of instruments and apparatus is only betwen Rs 25 lakhs and Rs 30 lakhs from educational institutions and research laboratories. Further, all the new materials that are purchased by manufacturers are already excise duty paid. As such, there will not be much loss if there is a complete waiver of excise duty on the instruments supplied to hospitals, educational institutions and registered R&D units as the recovery cost, if taken for the instrument industry separately, may be much more than the excise revenue.

- *MODVAT Facilities* MODVAT benefit is already available for the instrumentation industry in chapters 39, 40, 73, 84, 85 and 90 Since there are instruments made of wood, which are covered by chapter 44, but not covered under the MODVAT scheme, it is suggested that chapter 44 may also be covered under the MODVAT scheme to enable the industry to take advantage on the inputs used.

- *Goods sent for Display in any Fair or Exhibition in India* The Government of India has already issued notification No. 215/84-CE dated 9.11.84, amended by notification No. 200/85-CE dated 30.8.85, exempting 18 types of goods from payment of excise duty. For instance, computers, weighing machines, control equipments, falling under serial numbers. 8, 16, 18 respectively of the notification referred to above, are already exempt but instruments as a whole have not been exempt. It is suggested that all the products of instrumentation industry be exempted from payment of excise duty.

2.3d 100% Export-Oriented Units (EOU)

This scheme, introduced by the Ministry of Industry, has failed to take off for a variety of reasons. Notwithstanding the past record, it is possible to consider such a scheme again, provided care is taken to remove the obstacles of the past. The creation of EOUs can have the beneficial effect of generating a chain of subcontractor industries. We recommend:

- EOUs pertaining to instrumentation operate as system manufacturers, assembling their products from imported as well as local subsystems.

- EOUs be permitted free import of design, process technology and quality control procedures.

- EOUs be permitted to identify local industries capable of absorbing such technology, and freely pass to it such aspects as are needed for the fabrication of quality components.

- EOUs be permitted to subcontract to the local small-scale industries with under-utilised capacities.

- That the zone housing the EOUs be provided with proper infrastructure facilities like telephone and telex, and for holding import as well as export cargo.

- A liberal and enlightened policy with regard to the import of dies, jigs, fixtures, consumable raw materials.

2.3e Export

Now that great emphasis is being placed on exports, the following question can be raised: what may we expect from the instrumentation industry (other than the EOUs)? Considering that we would be late starters, (that is if we finally cut lose and start moving), it is difficult to envisage the export of discrete hitech instruments. However, one may expect the following:

- Export of teaching aids to the Third World countries
- Export of instrumentation subsystems to systems manufacturers in the advanced countries.

These objectives are sufficiently obvious and do not require further explanation. But certain problems relating to export merit attention.

- By and large, scientific instruments are exported as "smalls". They will continue to be so for some time to come, although the volume may increase.

- One has to depend on agents/distributors. Unlike in the case of, say, tea or textiles, there are various services to be rendered by the agents of scientific instruments, Exporters from Japan, America and Europe permit upto 25% agency commission. By contrast, the Reserve Bank of India does not permit remittance except of the order of 5% as agency commission, and that too declared in the customer's invoice.

This policy must change. (a) Discounts upto 20% must be permitted. (This alone can generate the interest of overseas distributors in Indian products). (b) NRIs must be permitted to act as agents since they understand the Indian scene, and can be expected to have a more sympathetic attitude to our industry. Government could however demand preliminary screening and empanelling.

2.3f Purchase Policy

To ensure that quality products are available in the area of instrumentation, the present purchase policy of the Government must undergo a radical change.

Instead of procuring on the basis of the lowest offer, procurement must be on the basis of the lowest technically suitable offer. In other words, the product selected must be capable of meeting all the performance requirements. Among those meeting this criterion, the one offering the best price advantage should be selected.

Wherever possible, procurement must be decentralised making the user responsible for the purchase.

2.3g Import Restrictions

There must progressively be tightening of imports. There is a constant tendency to exaggerate specifications of sophisticated equipment, often to just beat the limit of the Indian product and import what is required. The reasons why this happen at present are well-known. To prevent this,

- The Indian product must guarantee quality. This is possible.
- The Indian product must be price compatible. This is possible if the recommendations with respect to fiscal policy are duly implemented.
- The Indian product must be continually updated by aggressive and dynamic R&D. This has not happened in the past. But it must be made to happen!

In a nutshell, the essence of the section is that our instrumentation industry deserves a break. It is high time it got one. Given capital machinery and raw materials at international prices, backed by streamlined procedures and tariffs, our industry can well exploit the abundant skills already available to produce many of our needs. We must give it the chance. In any event, we have no other alternative!

2.4 Role of Government

In this Section we discuss the role of Government in promoting the suggested thrust programme. As already mentioned, there are several levels of Government involvement. Now Governmental agencies tend to be slow acting, notwithstanding the spirited enthusiasm of a select few who are always present. One is therefore concerned about the implementation of the suggested programme. Ideally speaking, one would like an organisational framework that is (a) highly motivated, (b) decentralised, and (c) extra-Governmental. However, the last mentioned is not feasible! Accordingly, a hybrid scheme, shown in *Fig. 3*, is suggested. In this, the Government acts through a special Directorate. Given the longstanding role of the DST in promoting instrument development, it is natural to propose that this Directorate be a part of the DST. At the same time, the proposed Directorate should be an apex body which, while taking in to account the interests of all Departments, has the final say. At present, inter-departmental differences about policies and implementation are all too common, unnecessarily retarding progress. To keep the Directorate on its toes, there must be a Council or a Board of eminent men, not necessarily drawn from the Government. This is the only way extra pressure can be brought, in case there are tendencies for slowing down.

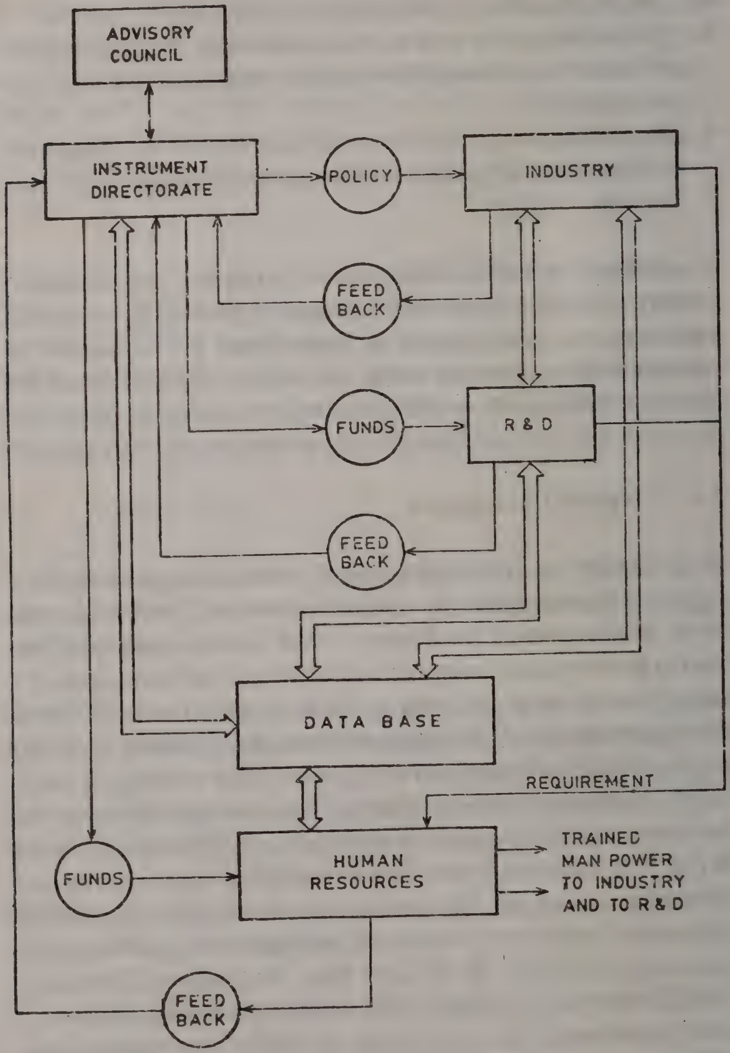


Fig. 3 The organisational framework proposed for the instrument directorate.

Turning to the role of the Government itself, at the highest level there is policy making. This relates to:

- Standing by the earlier declaration that the instrumentation industry is a key industry.
- Formulating custom and excise policies which are promotional in character.
- Permitting the private sector, especially small scale industries, not only to enter the hitech area but also to service defence needs wherever possible.
- Levying a cess as suggested in Section 2.3.
- Committing funds derived from the case for an aggressive R&D programme.
- Formulating an effective R&D strategy as discussed in Section 2.5.
- Organising a data bank (as amplified in Section 2.5).
- Launching a crash programme for the manufacture of some immediately needed instruments (Section 2.1).
- Planning the human resources (Section 2.7).

Elsewhere in the world, R&D has, and continues to play, a vital role in the development and the growth of the instrumentation industry. It cannot be any different in India. In view of its importance, we have devoted a separate section to R&D. Here we would like to suggest a few guidelines.

- Government must not hesitate to spend at least 1 to 2% of the import value on R&D. Extrapolating from figures for the present plan, the import bill on instrumentation during the 8th Plan could easily touch Rs 4000 crores. Therefore, an R&D expenditure of Rs 40-60 crores does not seem unreasonable at all. If there is a problem about funds (although there should not be, if the suggestions about levy of cess etc. are implemented), then a special 3% R&D levy can be made on every price of imported instrumentation, even if it otherwise becomes eligible for customs duty exemption. This money should be made available in to for R&D.

- In order to make efficient use of available skills and manpower, Government must commission R&D by giving directives to the laboratory concerned, and also accord priority.

- Government must accept joint R&D between industry (including private industry) and national laboratories, especially on major missions. This would not only facilitate subsequent productionisation but, during the R&D stage, permit the laboratory to obtain fabrication without investing on special machines (since the industrial partner is very likely to have such tools).

- Like the Harwell pattern, Government must permit the laboratories complete autonomy in the use of the R&D funds. At Harwell, for example, the laboratory can hire temporary staff on contract funds without Government approval, and bypassing routine procedures. The same applies to procurement. In the Indian context these might appear radical suggestions. But if we want a dramatic change we must be prepared to deviate substantially from existing policies which tend to cramp development excessively.

- Government must permit the laboratories to offer consultancy and collect fees directly. The fees must not go to individuals but, instead, to the laboratory, and the laboratory's Director must be free to use such funds for R&D activities at his discretion. Such a pattern has been tried out in the CSIR, and has been found to be successful. It is worth adopting across the broad (without, of course, jeopardy to the basic assigned tasks of the laboratory concerned).

- A part of the royalty earned out of products emerging from R&D must go to the laboratory, to be used by it in the same manner as the fees earned by consultancy.

The special Directorate already alluded to would be a nodal agency, coordinating suitably the requirements of various sectors - industry, defence, education etc. It would obtain and operate the R&D funds, monitor the progress of R&D, the technology transfer, technology import and unpacking, engage in technology forecasting, operate the data bank etc.

small wavelength meant smaller sizes of transmitter and receiver optics. However, the main drawback of the early line of sight communication links was their susceptibility to weather conditions. The alternative, namely communication through optical fibres, did not seem possible because of high loses in optical fibres. The breakthorugh came in 1974 when Corning produced low loss optical fibre from high purity materials. Since then there have been remarkable developments both in the optical fibre and in semiconductor laser technologies. The loss of optical fibres has been reduced to less than 0.3 dB/km at 1.5 micron wavelength (i.e., a 10 km long fibre will transmit 50% of incident light), and an even lower loss is predicted at longer wavelengths from new optical fibres under development.

Graded index fibres, in which the refractive index varies across the diameter of the fibre in a specific way, have reduced modal dispersion, thereby increasing the bandwidth of optical fibre communication links. Narrow linewidth single mode semiconductor lasers have also led to reduction in dispersion due to the material of bandwidth. Thus, it is possible to design and demonstrate an optical fibre communication link with more than a gigabit/second data rate. Similarly, the repeater spacing for optical link can be increased to as much as 100 km (for microwave cable links, the repeater spacing is a few kilometers), though with a lower data rate.

In the Western countries optical communication links are already replacing microwave cable links, particularly on trunk lines between telephone exchanges and between cities. Submarine optical fibre cables across the Atlantic Ocean are operational for the last few years. Japan also has an extensive optical communication network and is leading the semiconductor laser technology.

In addition to transmission of data, optical information processing and optical computers are related areas where major developments are expected in the near future. Optical information processing is already in use for fingerprint identification, processing of photographs taken by satellites and high flying aircraft etc. Optical computers, based on optical bistable devices, will offer a many fold increase in the speed of computing and also the capability to do parallel processing. The first optical computer is to be demonstrated soon in Europe where its development was taken up jointly by several laboratories.

Data storage is another area where higher density of data storage is possible by using optical methods. The storage medium is generally a thin film of metal whose optical properties, such as reflectivity, gets modified when illuminated with a powerful ''write'' laser. The lower power ''read'' laser reads the change in optical property as the required information. Since laser beams can be focussed to spots smaller than one micron in diameter it takes less than one square micron to record one bit of information. ie., 100 millions bits per cm^2. Laser video disc and compact disc are examples of such data storage in the entertainment market. The density of data storage is much higher for optical data storage discs than for magnetic data storage devices. However, the main drawback of optical data storage is that, so far, it is not erasable. Several laboratories are working to develop an erasable optical data storage disc, and such erasable optical discs are expected to come in the market within the next 2-3 years.

1.5 Laser Applications in Defence

Lasers play a major role in the modern weapon systems. Laser range-finders for tanks and artillery guns measure accurately the range of targets, thus giving the tank or artillery gun first hit capability. These range-finders use the Nd:YAG laser and can measure a range of up to 10 km with an accuracy of about 5 meters.

Lasers are also used for guiding weapons to the targets. For target designation, repetitively pulsed laser illuminates the target. The target scatters the laser light and the missile seeking the scattered light homes on the target. Most of the modern fighters and bombers are equipped with laser targer designators which use Nd:YAG lasers. Another laser guided weapon is the beam riding missile. In this weapon system a laser beam is pointed to the target. The missile follows the path of the beam to hit the target. A four quadrant detector in the missile detects deviation of the missile from the laser beam path and corrects the course of the missile.

Laser ring gyroscopes have replaced mechanical gyroscopes in most of the aircraft both civil and military, and in long range guided missiles. The main advantage of a laser gyroscope is that there are no moving parts; which permit its use as a strap down gyroscope. These gyroscopes use a He-Ne laser whose resonator is in the shape of a triangle. For such a laser, the frequencies of the two laser beams, one travelling clockwise and the other anticlockwise, differ, the difference being proportional to the rate of rotation of the laser. The technical problems associated with making a laser gyroscope are very severe and require the highest level of technology to solve them.

He-Ne lasers mounted on sten guns carried by infantry permit easy aiming of the gun, thus improving its effectiveness. Similarly, He-Ne lasers, or semiconductor lasers, mounted on rifles and guns simulate the firing of the rifle or gun while training the soldiers.

Very high power lasers are being considered as weapons for destroying missiles and low flying aircraft. The SDI programme of USA, more popularly know as 'Star Wars', depends heavily on poweful lasers to destroy Soviet nuclear missiles. It is envisaged that lasers installed in an orbiting satellite should be capable of emitting beams of gigawatts of power for a few seconds to destroy such missiles. Although such lasers have not yet been demonstrated, free electron lasers (FEL), chemical lasers and gas dynamic lasers can, in principle, give the required power. Even with the *existing* high power chemical and gas dynamic lasers, low flying aircraft and stationary missiles have been destroyed in tests.

1.6 Lasers for Nuclear Energy

Nuclear reactors which use enriched uranium offer some advantages over those using natural uranium. However, enriching uranium by conventional techniques, e.g gaseous diffusion or centrifuge, is a difficult and expensive technology. Laser isotope separation (LID) promises to be a cheaper way of enriching uranium.

The physical and chemical properties of isotopes of an element are almost identical, which make separation of isotopes difficult. However, tunable narrowband lasers permit separation of isotopes by using the minute difference in the spectroscopic properties of the isotopes. The absorption lines of the two isotopes, say U^{235}, U^{238}, have slightly different wavelengths. A narrowband tunable dye laser tuned to the absorption line of U^{235} will be absorbed only by U^{235}, and not by U^{238}. The excited U^{235} atoms are ionised by irradiating them with other suitable lasers and the ions of U^{235}thus produced are collected by applications of electric and magnetic fields. The feasibility of LIS of uranium has been demonstrated in several laboratories, and USA is building a prototype production plant for enriching uranium. This plant will use tunable dye lasers pumped by copper vapour lasers for excitation and ionisation of U^{235} atoms.

Lasers are playing an important role in the search for a viable way of tapping fusion power. To obtain power from the Deuterium Tritium (DT) fusion reaction, it is necessary to heat DT to a temperature of about 100 million K and to confine the hot DT for a sufficient length of time, to permit the DT to undergo fusion reactions. There are two approaches to achieve these conditions. In magnetically confined fusion (MCF), magnetic fields are used to confine the DT plasma, whereas in inertially confined fusion (ICF), the inertia of the plasma is used to obtain to confinement. Tokamak is an example of MCF whereas laser fusion is an example of ICF. In laser fusion, a spherical glass microsphere (typically 100 microns in diameter) filled with a mixture of D and T, is irradiated symmetrically by a powerful pulsed laser. The laser heats and ablates the glass shell resulting in compression and heating of DT gas inside the shell. Several laboratories are conducting experiments with powerful Nd glass lasers to demonstrate the feasibility of the scheme. The most powerful such laser is the NOVA laser in USA which in 20 beams gives a peak power of more than 10^{13} watts in a pulse of few nanosec duration. Since such lasers are technologically difficult to build only a few countries have programmes in laser fusion research.

2 Important Lasers and Their Characteristics

Although hundreds of media have been shown to work as lasers, not all of them have been found suitable for practical applications due to one or more reasons. Given below is a brief description of only the important lasers.

2.1 Optically Pumped Lasers

In optically pumped lasers, a suitable source of light, such as an arc lamp, a flash lamp or another laser is used to excite the lasing medium. The important optically pumped lasers are Ruby laser, Nd:YAG laser, Nd glass laser and the dye laser.

Flash lamp giving a light pulse of few hundred microsec duration is used for exciting Ruby, Nd:YAG and Nd Glass lasers. The laser output normally consists of a train of random pulses of a few microsec duration and a few KWatts of peak power. However, by introducing a mechanical or electro-optic or acousto-optic shutter in the laser resonator, it is possible to obtain a single pulse of several MWatt peak power and of a few nanosec in duration. This mode of operation is known as Q-switched mode. It is also possible to mode-lock the laser to obtain ultrashort duration pulses. Mode-locked ruby and Nd:YAG lasers give pulses typically of about 100 psec in duration whereas mode-locked Nd Glass laser gives pulses as short as five picosec in duration.

The output from these lasers can be amplified to get higher powers. For most applications, one or two stages of amplifiers are adequate. However, for obtaining very high powers, e.g. for laser fusion research, a large number of amplifiers may become necessary.

The dye laser, because of its tunability, is an important tool for spectroscopy, photochemistry, pollusion monitoring, isotope separation etc. The wavelength of emission of the dye laser depends on the dye used. With different dyes one can cover the entire spectral region from near UV to near IR. Although the dye laser can be excited by special flash lamps, for most applications the dye lasers are excited by another pump laser. The pump laser can be a nitrogen laser, a frequency double Nd: YAG laser, an excimer laser, a copper vapour laser or an argon ion laser. Depending on the characteristics of the pump laser, the output of the dye laser can be continuous, pulsed with nanosec pulse duration or pulsed with picosec pulse duration.

The linewidth of the dye laser is narrowed and its wavelength tuned by incorporating a dispersive element in the resonator of the dye laser. The dispersive element is generally a diffraction grating or a birefringent Lyot filter. Tunable dye lasers pumped by argon lasers, and with linewidth of less than 1 MHz ($3x10^{-5}cm^{-1}$), are commercially available. When mode-locked, dye lasers can produce pulses shorter than a picose (10^{-12}sec) in duration which can be further compressed to give pulses as short as 6 femtosec (10^{-15}).

2.2 Electrically Excited Lasers

Electric discharge excitation is the most widely used method of excitation for gas lasers. The important gas lasers are helium-neon laser (He-Ne), helium cadmium laser, CO_2 lasers, argon and krypton lasers, nitrogen lasers, excimer laser, and copper vapour and gold vapour lasers.

Helium-neon lasers can emit laser light at several wavelengths in the visible and near infra red. The most widely used wavelength is, however, 632.8 mm in the red part of the spectrum. For applications like alignment, scanning etc. He-Ne lasers of 1 MW power are adequate. However, for some applications like holography, He-Ne lasers of up to 50 MW are used.

In a He-Ne laser, a mixture of helium and neon gases is excited by electric discharge. Helium atoms excited to metastable states, on collision with neon atoms, excite the neon atoms selectively to specific energy levels and create population inversion required for lasing. The main technological problems of He-Ne laser production relate to sealing of the windows or mirrors on the laser tube. Soft seals which use resins tend to degas and contaminate the gas mixture. Hard glass to metal seals or glass fused seals are necessary to ensure long life of the laser tube.

The helium-cadmium laser, in which cadmium is the lasing medium, emits in the violet and ultraviolet region of the spectrum at 441.6 nm and 395.0 nm wavelengths. Commercial He-Cd lasers emit power up to 100 MW in the blue and 15 MW in the violet region. In these lasers, electric discharge heats the laser tube to create cadmium vapours. The discharge excites the cadmium atoms which then emit laser radiation. While designing the laser, care has to be taken to ensure uniform cadmium vapour density in the discharge region, to prevent the chemical reaction of the cadmium vapour with components of the laser tube, and to avoid deposition of cadmium vapour on the windows of the tube.

Helium-cadmium lasers are used for holography, Raman spectroscopy, blood analysers and cell sorters, high speed printing etc.

The carbon dioxide laser is undoubtedly one of the important lasers because of its high efficiency (15%) and high power capacity. The CO_2 laser emits in the infra red at 10.6 microns. In a typical CO_2 laser, a mixture of CO_2, N_2 and He is excited by electrical discharge. Nitrogen molecules get excited by the discharge and transfer their energy to the CO_2 molecules which then emit the laser radiation. The excitation of the CO_2 laser mixture can be either pulsed or continuous.

With continuous excitation, the power available from the CO_2 laser is limited to about 75 watts per metre of laser tube length. This limit is due to the heating of the gas mixture by the discharge, which results in increasing the population of the lower laser level, thereby reducing population inversion. To circumvent this limit, the gas is made to flow at high velocity through the discharge region to carry away the heat generated rapidly. Such fast flow CO_2 lasers are now commercially available; they give up to 5 kW of continuous power.

In the pulsed mode, the pressure of the laser gas mixture can be increased to one atmosphere or even higher. Because of the higher density of molecules, it then becomes possible to obtain very high power from the laser but in a short pulse. Such lasers, known as (transversely excited atmospheric pressure) TEA CO_2 lasers, can give a peak power of a few MW in a laser pulse of 500 nsec duration.

Low power CO_2 lasers find applications in medicine, processing of ceramics, plastics, cloth etc., and in R&D. High power (above 1 KW) $CWCO_2$ lasers are used for processing of metals. Pulsed TEA CO_2 lasers are used for R&R in spectroscopy, photochemistry and in laser fusion research. CO_2 lasers are also being used for range-finders in defence applications.

The argon laser emits in the green, blue and ultraviolet region of the spectrum at 514 nm, 457 nm and 351 nm respectively. Because these lasers can give cW power of up to 20 W, they find wide use in medicine, for eye and general surgery, in Raman spectroscopy, for pumping dye lasers, and for holography. Krypton lasers also give high power, but in the red part of the spectrum. This is advantageous for some surgical procedures. Argon and krypton lasers together give the three primary colours: red, blue, green, and are used for display.

The nitrogen laser is basically a pulsed laser emitting in the ultraviolet at 336.1 nm wavelength with a typical pulse duration of 10 nsec and peak power between 100 kW -1 MW. This laser is cheap, easy to construct and does not require any imported components. This lasers is used for pumping dye lasers, and for fluorescence studies.

Excimer lasers ar powerful UV lasers which have a high efficiency (greater than 1%) when compared to other UV lasers. Excimers are molecules which exist only in the excited state and do not exit in ground state. Thus the population of the ground state of the molecule is always zero, which makes it relatively easy to obtain population inversion and to get high efficiency. The excimer molecules most widely used are XeF emitting at 351 nm, XeCl emitting at 308 nm, KrF emitting at 248 nm and ArF emitting at 193 nm. Typical peak powers of 10-20 MW, typical pulse durations of 30-50 nsec and typical pulse repetition rates of 10-100 pps are available in commercial models.

Excimer lasers are used to pump dye lasers, for spectroscopy and photochemistry, in medicine for surgery, and in material processing applications.

The Copper Vapour Laser (CVL) is another efficient laser (1%-

efficiency) emitting at 511 nm and 578 nm in the green and yellow respectively. In a CVL, discharge in Helium gas, filled in alumina laser tube, heats the tube to about 1500°C. At this temperature, copper placed in the tube evaporates. The copper atoms of the vapour are excited by the discharge and emit laser radiation. Commercially available CVLs give average power of up to 40 watts, peak power of up to 100 kW, in a pulse of 30 nsec duration, and at repetition rates of upto 10 KHz.

Copper vapour lasers are widely used to pump dye lasers, for spectroscopy and photochemistry, for high speed photography, and for laser displays etc.

When copper is replaced with gold, one gets the gold vapour laser (GVL) which emits a red beam at 628 nm. This laser is important for photoradiation therapy for cancer treatment.

2.3 Semiconductor Diode Lasers

Semiconductor lasers are unique because of their small size (smaller than 100x100 micron), their high efficiency (nearly 50%) and the possibility to modulate the light directly by modulating the current through the laser. All of these properties are important for optical fibre communication and hence semiconductor diode lasers are universally used for optical communication. The wave length of emission of the semiconductor laser depends on the chemical composition of the semiconductor and the temperature of operation. The first generation of optical communication links used GaAlAs semiconductors for lasers, emitting at 0.92 micron because the technology of GaAIAs lasers was more advanced then. However, the lasers for the next generation of communication are required to emit at a wavelength of 1.3 micron or 1.55 micron where the fibre dispersion and absorption are respectively the least. By suitably adjusting the ratio of In, GaAs and P in the quaternery compound, InGaAsP, it is possible to obtain lasers operating at these wavelengths.

Another group of semiconductors, namely lead salts (II-IV compounds), are used to make laser diodes which, depending on the composition, emit in the wavelength range of 4 microns to 40 microns. A diode of particular composition can be tuned over a small wavelength region by changing its temperature. These lasers are used mainly for spectroscopy, pollution measurement etc.,

Semiconductor lasers working at shorter wavelength extending in the red are now available. Lasers emitting at about 0.8 micron find applications in laser printers and scanners. Optical disc readers, and related applications.

Semiconductor diode lasers emitting in the red have been demonstrated in laboratories in Japan and are expected to be commercially available within next 2-3 years. They will then replace the He-Ne laser in most applications.

3 Status of Laser Technology in India

3.1 Historical Background

The importance of lasers was recognised by the scientific community in India fairly early and several institutions such as BARC, NPL, IIT, Kanpur and IISc initiated R&D programmes, although modest ones, in this area in the mid-sixties. The first laser fabricated in India was a gallium arsenide semiconductor laser, developed at BARC in 1964. Although the GaAs slice for making this laser was imported, the entire processing of the laser diode, which included forming the p-n junction, forming ohmic contacts and forming the resonator by appropriate cleaving of the slice, was developed at BARC. This laser was used in 1965-66 to establish an optical communication link between BARC and TIFR, a distance of 20 km. In 1964-65, IIT, Kanpur, imported a ruby laser from USA and conducted some studies on the characteristics of the laser. This laser was later used for studying Raman scattering.

The Indian programme of laser R&D was soon expanded. In 1967-68 BARC undertook the development of several other lasers: ruby, Nd glass, CO_2 and He-Ne. The ruby laser was operated in 1968 and was used in the first rangefinder developed at BARC in 1969-70.

IISc and NPL also took up the development of the He-Ne laser in 1966-67. The operation of indigenously built He-Ne lasers was more or less simultaneously demonstrated by BARC, NPL and IISc. While BARC discontinued further work on He-Ne lasers then (although it was taken up later again), and concentrated on solid state lasers and CO_2 lasers, NPL and IISc continued their efforts to develop the know-how for the He-Ne laser. The know-how was transferred by NPL to a private sector manufacturer, and by IISc to ECIL, around 1974-75.

Since the sixties the laser and related R&D programmes have expanded considerably and today encompass many of the important areas of laser applications. However, compared to the magnitude of similar efforts in Western countries, or even in China, Indian efforts are very modest. Even then, Indian scientists have been able to make their mark in the international scene in some of these areas.

3.2 Laser Technology in India

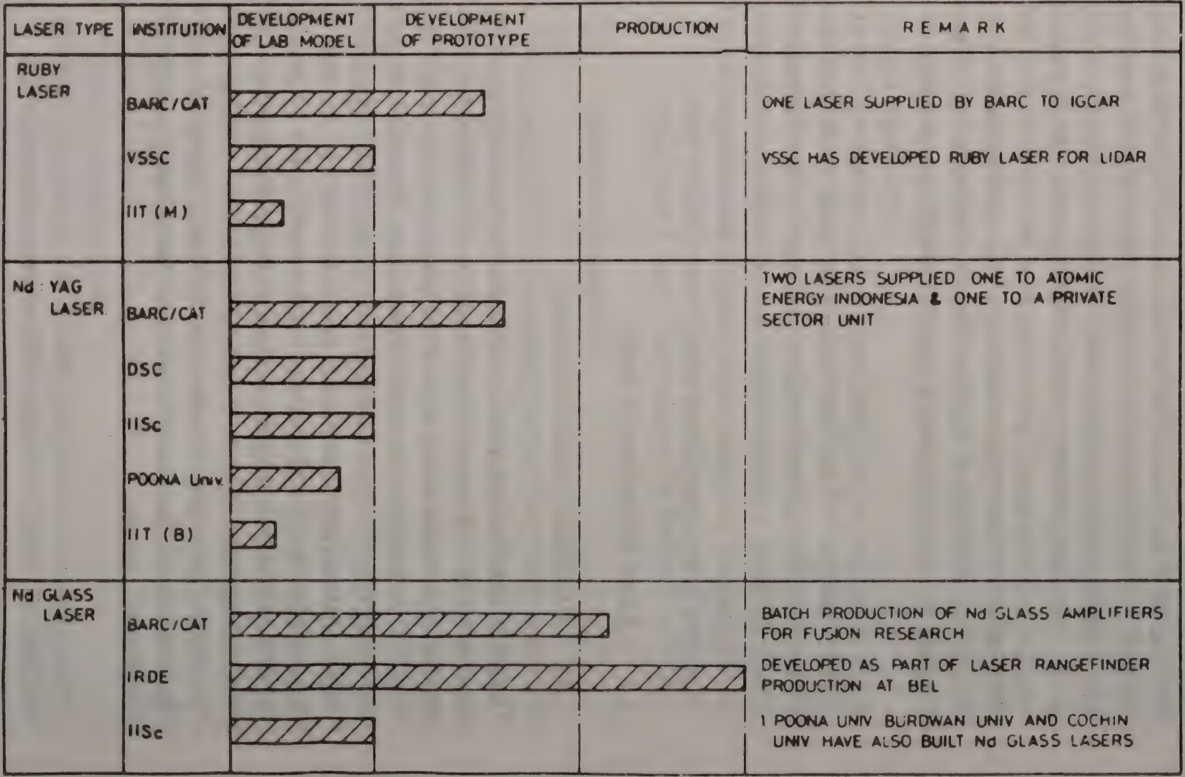
3.2a A Laboratory-wise Description

Although today a large number of laboratories have R&D programmes in lasers and related areas, the work on the development of technology of lasers is very small. It is important at this stage to define what one means by development of technology. Several laboratories have built lasers for their own use. In most cases these lasers are not engineered properly. Such lasers generally cannot be operated by anyone other than the person who has developed it. For the purpose of this report such development efforts are not considered to be taken as technology development. In the bar chart (Table 1) which indicates the status of technology of various lasers in India, laboratories which have developed lasers, but not engineered them properly, are listed in the remarks column.

The laboratory with the largest effort for developing laser technology in India is. BARC. The laser R&D programme at BARC was expanded systematically to cover development of many important lasers. These include He-Ne laser, He-Cd laser, N_2 laser, Ar laser, CO_2 laser, copper vapour laser, ruby laser, Nd:YAG laser, Nd glass laser

Table 1

The Status of Laser Technologies in India



LASER TYPE	INSTITUTION	DEVELOPMENT OF LAB MODEL	DEVELOPMENT OF PROTOTYPE	PRODUCTION	REMARK
RUBY LASER	BARC/CAT	▨	▨		ONE LASER SUPPLIED BY BARC TO IGCAR
	VSSC	▨			VSSC HAS DEVELOPED RUBY LASER FOR LIDAR
	IIT (M)	▨			
Nd : YAG LASER	BARC/CAT	▨	▨		TWO LASERS SUPPLIED ONE TO ATOMIC ENERGY INDONESIA & ONE TO A PRIVATE SECTOR UNIT
	DSC	▨			
	IISc	▨			
	POONA Univ.	▨			
	IIT (B)	▨			
Nd GLASS LASER	BARC/CAT	▨	▨	▨	BATCH PRODUCTION OF Nd GLASS AMPLIFIERS FOR FUSION RESEARCH
	IRDE	▨	▨	▨	DEVELOPED AS PART OF LASER RANGEFINDER PRODUCTION AT BEL
	IISc	▨			1 POONA UNIV BURDWAN UNIV AND COCHIN UNIV HAVE ALSO BUILT Nd GLASS LASERS

Table 1 (*Contd.*)

LASER TYPE	INSTITUTION	DEVELOPMENT OF LAB MODEL	DEVELOPMENT OF PROTOTYPE	PRODUCTION	REMARK
He-Ne LASER	BEL	▨	▨	▨	2mW 632·8 NM LASERS UNDER PRODUCTION HARD SEAL TECHNOGY YET TO BE DEVELOPED.
	NPL	⬚	⬚	⬚	KNOWHOW TRANSFERRED TO PRIVATE SECTOR UNIT DEVELOPMENT AND PRODUCTION DISCONTINUED.
	IISC	⬚	⬚	⬚	KNOW-HOW TRANSFERRED TO ECIL. DEVELOPMENT AND PRODUCTION DISCONTINUED
	BARC	▨			LAB MODELS OF UPTO 50MW. POWER
	IGCAR	▨			50mW. POWER LAB MODEL
	IAT	▨			50mW. POWER LAB MODEL
	IIT (K)	▨			
ARGON LASER	BARC	▨			4 WATT ARGON LASER
	IIT (K)	▨			300mW. ARGON LASER

Table 1 (*Contd.*)

LASER TYPE	INSTITUTION	DEVELOPMENT OF LAB MODEL	DEVELOPMENT OF PROTOTYPE	PRODUCTION	REMARK
CO_2 LASER UPTO 100W	BARC/CAT	▨	▨	▨	KNOWHOW TRANSFERRED TO CEL. PRODUCTION DISCONTINUED. DEVELOPMENT CONTINUES.
	JYOTI LTD.	▨	▨	▨	DEVELOPMENT & PRODUCTION DISCONTINUED.
					SEVERAL OTHER LABORATORIES NAMELY IIT(K), IISc, IIT(M), BHU, POONA UNIV. HAVE BUILT SUCH LASERS
CO_2 LASER FAST FLOW 1KW	BARC/CAT	▨			
CO_2 LASER PULSED TEA	BARC/CAT	▨	▨		IRDE AND POONA UNIV. HAVE ALSO BUILT SUCH LASER.
CO_2 LASER GAS DYNAMIC	DSC	▨			
DYE LASER	BARC/CAT	▨	▨		SEVERAL OTHER LABORATORIES NAMELY COCHIN UNIV., IIT(B), IIT(K), IIT(KH) HAVE ALSO BUILT DYE LASERS.
	BHU	▨			
	POONA UNIV.	▨			
He - Cd	BARC	▨			100 mW OUTPUT POWER
	IGCAR	▨			

Table 1 (*Contd.*)

LASER TYPE	INSTITUTION	DEVELOPMENT OF LAB MODEL	DEVELOPMENT OF PROTOTYPE	PRODUCTION	REMARK
NITROGEN LASER	IIT (K)	░	░	░	KNOW-HOW TRANSFERRED TO CEL DEVELOPMENT AND PRODUCTION DISCONTINUED.
	BARC/CAT	▨	▨		
	BHU	▨			SEVERAL OTHER LABORATORIES INCLUDING COCHIN UNIV. KARNATAK UNIV. MARATHWADA UNIV. POONA UNIV. M. DAYANAND UNIV. IIT(B), IIT (KH) HAVE ALSO BUILT N_2 LASERS
	ANNA UNIV.	▨			
SEMICONDUCTOR LASER	SPL	▨	▨		EXACT STATUS NOT KNOWN
EXCIMER LASER	IIT (K)	▨			
	BARC/CAT	▨			
COPPER VAPOUR LASER	BARC/CAT	▨	▨	▨	BATCH PRODUCTION UNDERTAKEN AT CAT.
	IIT (K)	░			WORK DISCONTINUED.

and dye laser. Some amount of engineering has gone in all of them and several of them have been supplied to other laboratories where their performance has been satisfactory. Even then it is considered necessary to do further prototype development for some of these lasers before the technology is ready for production.

BARC has developed, with assistance from IAT, a 50 MW laser for Raman spectroscopy. Similarly, a 100 MW He-Cd and a 4 W argon laser were developed for the same application. The design of the Hw-Ne and He-Cd lasers were given to IDCAR when these lasers were successfully built.

BARC has developed various types of CO_2 lasers. The know-how for a 100 watt CO_2 laser, which had options for pulsed operation and tunability, was given to CEL. As a part of the know-how, two CO_2 lasers were fabricated by BARC and given to CEL. These lasers were supplied by CEL to two laboratories and are operating successfully. Due to a lack of demand, CEL has discontinued production of this laser.

BARC has also worked extensively on the technology of pulsed TEA CO_2 lasers. A number of such lasers have been built and are used in BARC. The most recent development is a high rep. rate TEA CO_2 laser which gives 1 joules 3 MW pulses at 50 pps.

BARC has also worked extensively on the technology of solid state lasers, namely, ruby laser, Nd:YAG laser and Nd glass laser. Several such lasers have been built and supplied to other users. BARC is currently building a four beam 1000 joule, 1 terawatt (10^{12}watts) Nd glass laser for fusion studies. The technology of dye lasers, pumped by N_2 laser and CVL, has also been developed at BARC. A line width of 0.00 cm^{-1}, and an efficiency of 12%, from Rn6G dye laser pumped by CVL has been achieved. Frequency stabilisation of dye laser has also been developed. Two such lasers have been supplied to other users in BARC, where the performance has been satisfactory.

BARC had recognised lasers as a thrust area and had planned to expand the work in a big way. Due to some limitation at BARC for

Here we would mention that the 31 months guarantee period is essential because this is the period during which the London Chamber of Commerce itself is liable. It comprises the carnet validity period of 12 months, plus a further 12 months during which any claims against the carnet must, under the international convention, be received, plus a 7 months' allowance for finalising claims.

A bank or insurance company guarantee is a separate contract between the guarantors and the issuing Chamber of Commerce.

For regular users of the carnet scheme it could be advantageous to use a 'continuing guarantee', thus eliminating the need for individual arrangements. Further details of this time-saving facility are obtainable from any issuing chamber.

Under no circumstances will a carnet be issued until the appropriate fee and deposits, or guarantee, are received.

Preparing the forms When applying for a carnet, the issuing Chamber will supply you with appropriate forms for your completion.

When preparing the forms it should be borne in mind that, as with all customs documentation, they must be completed correctly and in full.

When completing the general list it should be remembered that such general terms as "machinery", "instruments", "textiles", etc. are insufficent. The list must be comprehensive and itemised. All serial numbers and other identifying marks, etc. must be shown. It is also necessary to show the country of origin and value against each item and a total value.

Consumable or other disposable goods such as leaflets, brochures, etc. cleaning materials, small quantities of paints, oils, etc. should not be entered in the list of goods. Unmounted gem-stones are not eligible to be termed "commercial samples" in a carnet and only a reasonable number of identical items of samples are allowed. Goods of foreign origin may be included on a carnet but the issuing Chamber will require a statement to the effect that the United Kingdom Customs Duty has been paid on them. Foreign goods temporarily imported into the UK under a customs temporary importation concession do not qualify for inclusion in a carnet.

If the general list of goods to be covered by the carnet is to be typed separately on plain paper, it must be prepared to the same format as the general list on the carnet.

This may only be done if there is insufficient room under the general list on form BIA.

If a separate list is prepared the backs of all forms should be left blank.

Copies of this list may be duplicated to the required number by any indelible reprographic means e.g. photocopying.

The number of items must be serialised and totalled in the appropriate space. The values of each item must also be listed against the total shown - in figures and in full in words - in the required box on the form.

When the carnet has been issued, the list of goods, shown on the back of the green form cover (general list), cannot be amended in any form whatsoever. Failure to comply with this regulation will mean delay in the discharge of the carnet, and will incur a regulation fee. Any deviation from the goods shown on the general list must be noted by the customs and excise in the certificate box on the green front cover and duly stamped. The goods shown on the general list must be altered.

Note: Photocopying the forms themselves is not permissible.

The Counterfoil/Voucher These should be completed and they all follow the same basic format. The number of vouchers to be completed depends upon the nature and the purpose of the journey that the goods are to undertake.

Yellow Vouchers - One exportation and one re-importation form must be prepared each time the goods leave and re-enter the country.

White Vouchers - One importation and one exportation form must be prepared for each country to be visited - per trip.

Blue Vouchers - Two transit vouchers must be prepared for each country to be crossed in transit/or for each exhibition/fair etc. in which you are participating.

Thus, for example, if your goods were travelling from UK to France (for demonstration) stopping off in Germany (for demonstration) and then to Italy for a Trade Fair and returning by the same route without stopping off, the complete carnet would comprise:

1 pair of yellow vouchers (export/re-import)
2 pairs of white vouchers (import/export)
3 pairs of blue vouchers
plus the green covers.

If you are uncertain of the number of forms you have to complete, you must seek advice based on the complete itinerary.

The completed cover and vouchers should be forwarded to in close leaf form (please do not fold) with the application form, issuing fee and correct security. The documents will be validated and returned without delay.

Please note that it takes 24 hours to process the carnet.

Please allow as much time as possible for the carnet to be issued particularly during the period March - October.

Using the Carnet

Immediately upon receipt, the carnet cover should be signed by the holder - it is not valid without this signature. Failure to do so will mean inconvenience at a customs post and, inevitably, a claim for customs duty being received.

It is necessary for the goods to be examined by the customs before departure and to note the fact on the carnet cover. This may be carried out at the departure point or at your own premises.

It is recommended that this examination be carried out at your address by appointment with customs, particularly if the goods are valuable, fragile, bulky, etc. or if they are being despatched abroad unaccompanied.

At the departure point, if the goods were previously examined, the Customs Officer will remove the first yellow voucher and endorse, stamp and sign the remaining counterfoil. Thereafter, at each subsequent customs post, a voucher will be detached and the counterfoil endorsed and signed etc. Finally, upon return to the country, the last yellow voucher will be detached and the counterfoil signed.

You must ensure that this simple procedure is carried out at every frontier or customs point. A claim for duty will certainly be received if this simple "entry and exit" routine is not observed.

When the carnet has been used, or when its validity is due to expire, it must be returned to the issuing Chamber immediately to enable it to be discharged. If the Carnet has been correctly used, the Chamber will conditionally discharge it and return the duty deposit or guarantee.

Should the carnet conditions not have been observed for some reason then it will be necessary for it to be "regularised" with foreign customs. This process could involve considerable delay in repayment of your deposit - in full or in part, and the payment of duty and/or fees etc. all of which must be reimbursed by the carnet holder. In addition a fee will be payable to help cover administration costs.

As previously stated, each carnet is valid for 12 months from date of issue and it cannot be extended or renewed. However, all or part of the goods enumerated in the master list in the carnet may be exported and reimported as many times as you wish during the validity period.

Extra vouchers, additional to those originally provided, can be validated by the issuing Chambers by returning the Carnet with the newly completed vouchers. In these circumstances, the used counterfoils in the carnet must not be removed although the Chamber may, if it so wishes, retain them for processing and safekeeping.

If the carnet itself is lost or stolen you should immediately notify the local police and/or customs of the occurrence and obtain a covering statement from them.

To help you on your way

In your own interest always ensure - insist if necessary - that the carnet voucher and counterfoil is properly processed at each frontier crossing.

Carefully note the period of temporary importation allowed by the foreign customs upon entry. Generally it is 12 months for commercial samples; 6

months for exhibition goods and professional equipment and often only days for goods in transit through a country. Never exceed the stipulated period; otherwise duty will be payable.

The use of a carnet does not absolve the holder from observing the customs regulations of the countries operating the scheme.

We recommend that your goods are covered by insurance during their journey, not only for their full value but also including the duty.

Where goods are of a sophisticated or complicated nature, or are not easily recognisable, it is sound policy to carry a copy of the list translated into the appropriate language(s). This will help the foreign customs officer make a speedy examination.

Not all Customs posts are open for the transit of goods for 24 hours a day, nor are they all able to process carnets. If you intend crossing a frontier outside normal hours, or if you are off a main route, it is a wise precaution to check in advance that the customs will be available to process you through. This applies particularly to travellers by road.

To avoid difficulty with the customs authorities abroad, it would be helpful if you could note the place, date, time and, if possible, the name or number of the customs officer concerned. This information will help in regularising the matter later.

The London Chamber of Commerce and all issuing Chambers in U.K. reserve the right to refuse to issue a carnet to any applicant at any time without indicating any reason.

Finally......

Should any further information be required concerning ATA Carnets or allied subjects do not hesitate to contact any issuing Chamber in the United Kindgom or the London Chamber of Commerce and Industry Export Documents Service Department - Carnets, 69 Cannon Street, London EC4N 5AB or telephone 248 4444. Hours 0930 - 1230 and 1330 - 1630.

(This document was issued by the London Chamber of Commerce and Industry in May 1974).

7

Robotics and Manufacturing Automation

Robots fulfil an important role in industry. They do simple and repetitive jobs more steadily, more reliably, and more uncomplainingly than a human could - or should.

Isaac Asimov in his foreword to Robotics in Practice, *Anchor Press, 1980.*

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7

Robotics and Manufacturing Automation

Preamble

Maximising productivity to face international competition is the vital issue engaging the attention of every manufacturing organisation around the world. There is now an increasing awareness of the imperatives for improving productivity in all walks of life in India as well, and, indeed, the Government is making determined efforts through its policies and directions to make rapid strides to catch up with the advanced countries. Manufacturing technology, a key factor in attaining high levels of productivity, is today going through, what may be called, the third Industrial Revolution, benefiting from the rapid progress achieved in the areas of computers, robotics, expert systems, intelligent sensors and controls, and information and communications technology. ■

1 Overview of Automated Manufacturing and Robotics

1.1 Automated Manufacturing

There are two major types of automated manufacturing: flow-line manufacturing and batch manufacturing. In flow- line manufacturing, dedicated capital-intensive equipment is designed for high volume production of a single product. This has automated monitoring and control systems using distributed computer technology. High volume production of discrete components such as automobiles, two wheelers, television sets, microcomputer systems, aircraft, etc, using highly specialised dedicated equipment, popularly known as hard automation, has proved its effectiveness. In stable-market high-volume environments, hard automation and its computer-implemented clones would continue to be the core technologies.

Batch production, as distinguished from flow-line manufacturing, represents a large proportion of manufacturing activity in metal cutting, electronic, plastics, ceramics, wood and garment industries. The Automated manufacturing technology (AMT), using computer controlled machine tools and automated material handling equipment, and supervised by a central computer, offers much promise in batch production. This includes high quality, accuracy and repeatability of the product, increased machine utilisation, reduced lead times, reduced inventory, lower labour costs and quicker response to new product design. In essence, AMT offers the potential advantages of automation in the batch production arena, where hard automation was not an economic proposition, by providing economies of scope rather than economies of scale. In addition, it offers the prospect of being able to absorb market uncertainties through its flexibility.

Two streams of applications of information technology to manufacturing can be identified. The first comprises direct applications where the computer, or a network of computers, monitors and controls the hardware in a manufacturing plant, such as machine tools, inspection machines, robots and automated guided vehicles, which physically transform or transport or assemble components. Indirect applications include computer aided design (CAD), production planning and control, inventory control, marketing, sales and other factory management systems used for management of production. Business software such as materials requirements planning (MRP-I), manufacturing resources planning (MRP-II), just-in-time techniques (JIT) and optimised production technology (OPT) is available for indirect applications. Automated manufacturing technology provides the hardware for direct applications and is highly capital intensive. Computer Integrated Manufacturing (CIM) includes both types of applications.

Table 1

Partial List of Machining FMSs in Use in the United States

User	Vendor	Year installed	Volume[b] & number of parts	Types of parts
Sundstrand Aviation	White-Sundstrand	1967	na[a],na	Aluminium pump parts
Ingesoll-Rand	White-Sundstrand	1970	20,000[b],14[c]	Hoist and motor cases
Rockwell	Kearney & Tracker (K&T)	1972	25,000[b],45[c]	Automotive axle carriers
Allis-Chalmers	K & T	1970,1973	23,000[b],8[c]	Agricultural equipment
Caterpillar	White-Sundstrand	1973	66,000[b],6[c]	Crank case housings, covers
AVCO-Williamsport	K & T	1975,1978	24,000[b],9[c]	Aircraft engines
AVCO-Lycoming	K & T	1979	15,000[b],10[c]	Turbine engines
Caterpillar	Giddings and Lewis	1980	na, na	Construction equipment
John Deere	K & T	1981	5000[b],8[c]	Farm equipment
General Electric	Giddings and Lewise	1981	5600[b],7[c]	Motor housings
Detroit Diesel Allison	White-Sundstrand	1983	na, 40[c]	Transmission housings

[a] information not available.

[b] total number of parts per year machined on system.

[c] number of different part types machined on system.

1.2 Developments Around the World

Recent studies indicate that the growth of AMT in the form of flexible manufacturing systems (FMS) has been steady. A typical FMS comprises versatile NC machines, with material integration provided by an automated material handling system, and with information integration provided by a local area network. The histograms in *Fig. 1* indicate that the widespread interest shown in the technology is being turned into projects by an increasing number of manufacturing organisations. Table 1 gives a partial list of flexible manufacturing systems currently in operation in the USA. Available information on investment in AMT, and also on reported savings in operating cost, is shown in Tables 2-5.

1.3 Robotics

Industrial robots are being increasingly used in several engineering applications including manufacturing. Tasks such as welding, spray painting, maching loading, material handling and assembly constitute the major uses of robots on the factory floor. Recent advances in machine vision and expert systems and their use in the development of intelligent robots have made robots versatile and integral parts of the automated factory. Indeed the number of robots used has become synonymous with high productivity. There is also a widespread use of robots in hazardous environments such as toxic chemical industries, assembly of explosives, deep-sea, underground, high-altitude and mountainous terrains, cold climates and nuclear reactors. Table 6 shows the number of robots used in various countries around the world.

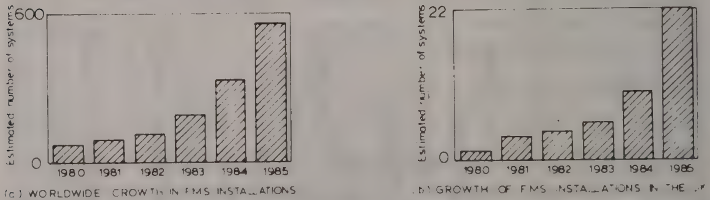

Fig. 1 (a) Worldwide growth in FMS installations, (b) Growth of FMS installations in the UK.

Table 2

Hardware Investment and Reported Savings in Operating Costs for Selected Kearney & Trecker Machining FMS

User	Cost (1982$) (million)	Product volume and part variety	Reported comparisons with old system
Rockwell (truck axles)	$5.6	24,000[b],45[c]	1/4 floor space; setup costs virtually eliminated
AVCO-Williamsport (aircraft engines)	$8.4	24,000[b],9[c]	1/3 floor space; 1/4 labor; 1/2 number of part holding devices
John Deere (tractor components)	$18	50,000[b],8-12[c]	Cost estimates of FMS: $18 million; dedicated transfer line: $28 million
Mask Truck (truck components)	$5	65,000[b],5[c]	Cost estimate of FMS about the same as estimate for dedicated transfer line, with comparable cycle time, less flexibility
Caterpillar[a] (construction equipment)	$5	8000[b],8[c]	Total transit time through system: Old system: 8.5h New system: 0.3h

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[a] This system is a semiflexible transfer line. All others listed here are flexible manufacturing systems.

[b] Total number of parts machined on system.

[c] Number of different types machined on system.

Table 3

Hardware Investment and Reported Savings in Operating Costs for Machining FMS at General Electric, Erie

Comparison	Old machining system	New machining system
Number of machines	29	9
Total production worker requirements for two shifts (operators, supervisors, and maintenance)	86	16
Typical number of machines loadings required to complete one part	10-11	4-5
Maximum annual output for family of seven parts	4100	5600
Average in-process time for a part	16 days	16 hours
Productivity change (total factor)	Base	+240%

Table 4

Hardware Investment and Reported Savings in Operating Costs for Machining FMS at Yamazaki Machinery Works

Plant	Yamazaki Machinery Works Ltd., Nagoya, Japan
Process	Machining
Products	Parts for numerically controlled machine tools and robots
Total cost	$20 million
Total employment	13
Comparisons	A conventional machining system with similar production volume would require 215 workers and nearly four times as many machines. Average in-process time per part was reduced from three months to three days. Over a five-year period, the plant is expected to be 15 times more profitable than a conventional plant of its size.

Table 5

Hardware Investment and Reported Savings in Operating Costs for Machining FMS at Fanuc Ltd.

Plant	Fanuc Ltd., Fuji complex, Japan
Process	Machining
Products	Parts for machine tools and robots
Total cost	$32 million
Comments on hardware	30 machining centres, consists of computer-controlled machine tools loaded and unloaded by robots, along with material-handling robots, monitors, and programmable controllers.
Employment	About 100
Comparison	The plant is about five times more productive than its conventional counterpart. It would probably take ten times the capital investment and ten times the labour force to produce the same output with a conventional plant.

Table 6

Number of Robots in Use Worldwide (1987)

World	1,20,000
Japan	67,000
U.S.A.	14,000
West Germany	6,600
France	3,400
Italy	2,700
U.K.	2,600
Sweden	2,400
Canada	700

1.4 R & D Investments Abroad

In several countries around the world, both the Government and the industry have initiated R & D programmes in this area with investments of billions of dollars. Notable among these countries are Japan, United States and the European Common Market countries. The areas considered include development of new materials, new cutting processes, machine tools, CAD/CAM integration, material handling equipment, computer and communication standards, computer control systems, expert systems for process planning, scheduling and real-time control, and new organisational and managerial structures for running future factories. On the education front, almost every university in the West has started a centre or a department on CIM with sponsorship from the industry and the Government.

1.5 Current Status of the Indian Industry

The diffusion of AMT in newly industralised countries (NICs) has been less pronounced than in developed countries. Table 7 shows the density of units (number per million of employees) of numerically controlled (NC) machine tools, computer aided design (CAD) systems and robots in five NICs (Brazil, India, Korea, Singapore and Yugoslavia) and five OECD countries (FRG, Japan, Sweden, UK and USA). Table 8 indicates the actual number of AMT elements in India.

Table 7

Relative Diffusion of AMT in NICs and OECDs (1984)

	NICs (1)	OECDs (2)	(2)/(1)
NC Machine Tools	1,665	14,230	8.5
CAD Systems	498	4,114	8.3
Robots	96	4,122	43.0

The only FMS in our country is installed at the Heavy Alloy Penetrator Project (HAPP) at Trichy. This system has intelligent CNC

Table 8

AMT elements in India (1985)

NC Machine Tools	CAD systems	FMS
1178	700	1 (planned)

work centres, integrated with a tool management system and loading/unloading gantry, and is capable of uninterrupted operation for more than one shift. Material integration at the shop floor has been achieved by introducing automated guided vehicles (AGVs), and information integration by a supervisory computer. Inspection through electronic gauges is integrated with the manufacturing process. Further, an integrated factory management information system is being adopted to interface with the automated manufacturing facilities. The management intends to extend automation to other manufacturing operations in the factory, aiming to achieve plant-wide integration.

Robots and other material handling equipment are being developed at Bhabha Atomic Research Centre (BARC), Bombay, for nuclear applications. The remote handling systems developed and deployed at various nuclear plants under the Department of Atomic Energy (DAE) have freed the country from dependence on foreign suppliers.

Apart from the above exceptions, current manufacturing technology and practice in our country is plagued by disappointingly low levels of productivity, quality and reliability, and high input costs. The productivity of Indian firms is low in capital, energy and material use, and in labour. Productivity depends on several factors of which technology is the most dominant. Much of the technology in India is imported. Unfortunately, Indian firms have not often absorbed and improved on the imported technology. Consequently a gap exists between the technologies existing in India and in developed countries.

In respect of manufacturing automation products, our contributions are minimal. CNC machines, conveyor systems, assembly robots, industrial robots, automated guided vehicles, local area networks and communication media are yet to make an impact in most industrial environments in the country. Software products such as materials resources planning (MRP), manufacturing resources planning (MRP II), just-in-time (JIT), computer aided production planning (CAPP), and total quality control (TQC), which are routinely used in most countries, including Brazil and South Korea, have not yet caught the attention of the manufacturing community in our country.

According to Government sources, the reasons for high cost and low productivity are: (a) poorly defined goals and objectives of organisations, (b) improper equipment/ technology selection (c) indifference to changes in technology and market place, (d) lip service to in-house R&D, and (e) protected markets.

It is imperative that we should upgrade the technology and management in our factories,

- to meet the needs in sensitive areas such as defence and nuclear applications,
- to be able to export goods of internationally comparable quality at competitive prices,
- to meet the needs of the domestic market without making it protectionist, and
- to produce high quality consumer goods at low cost while conserving natural resources and energy, and at the same time contributing to the employment potential.

2 Automation and Robotics for Nuclear Plants

2.1 Introduction

In nuclear plants such as power reactors, fuel reprocessing or radioactive waste disposal plants, there is a need to carry out a variety of surveying, inspection, maintenance and repair jobs in a highly radioactive and hazardous environment. Remote handling systems are therefore imperative in nuclear establishments.

2.2 Pilot Project for Development of Robots for Nuclear Plants

The objective here is to build a robot-centred plant through indigenous manpower and resources. This will demonstrate the integration of mechanisms, electrical drives and controllers, computer hardware and software, synchronised conveying systems etc., resulting in automated and readily reprogrammable robot workstations. This project can be implemented in three phases:

Phase I

Stepper-motor driven light-duty robots, whose prototypes have already been built in BARC fully indigenously, will be improved and used at the Tarapur Complex of DAE for production and handling of reactor fuel assemblies (see Table 9).

Table 9

Cost Estimate (Phase I)

Building and building services	Already available at Tarapur
Mechanical fabrication (robots, conveyors and miscellaneous hardware)	Rs 8 lakhs
Stepper motors	Rs 1 lakh
Motor controllers	Rs 1 lakh
Microprocessors & computer hardware	Rs 2 lakhs
Project charged design, drafting, mechanical assembly and computer software services for one year	Rs 4 lakhs
Overheads	Rs 1 lakh
Total cost	Rs.17 lakhs

Phase II

In the second phase, robots with relatively greater handling capacity

(5 to 10 kg), which are servo-motor driven, and with closed loop control, will be employed. Also, the robots will be sensor-supported to some extent, illustrating the principles and practical applications of artificial intelligence (see Table 10).

Table 10

Cost Estimate (Phase II)

Land, building and building services (proposed location : Bombay, but outside BARC premises)	Rs 20 lakhs
Mechanical fabrication (Robots, conveyors, miscellaneous hardware)	Rs 15 lakhs
Servo motors and servo drives	Rs 5 lakhs
Sensor - related hardware and microprocessor systems	Rs 15 lakhs
Microprocessors and computer hardware	Rs 5 lakhs
Project charged design, drafting, mechanical assembly and computer software services for two years	Rs 10 lakhs
Overheads	Rs 3 lakhs
Total cost	Rs 73 lakhs

The total cost of Phase I and Phase II, at 1987 prices, is Rs 90 lakhs. Assuming a total cost escalation of about 15% during the execution of the projects, the cost would then be approximately Rs 104 lakhs.

Phase III

In Phase III, advanced robots capable of inspecting, maintaining and repairing nuclear power reactors under human supervision, and robots capable of carrying/ handling industrial loads/jobs of greater weight (more than 100 kg), with multiple sensors and several degrees of control, are required to be developed.

This programme requires a close interaction with the user industries so as to draw up the specifications of a few selected models which can be widely used. This will be a major national effort; and it may be possible to develop the nuclear robots at BARC and the industrial robots at CMTI/CMERI. The detailed cost of this phase is to be worked out, but the experience in USA suggests that it will be about Rs 10 crores.

3 A Flexible Manufacturing System (FMS) for Prismatic Components

3.1 Introduction

Recent surveys conducted in developed countries indicate that the major sectorwise FMS/CIM users are: (a) Automotive (b) Industrial machinery (c) Agriculture/construction equipment and (d) Aerospace/ defence. The Automotive sector has about 40-50% of the total number of installations. The initial application to trucks and buses has now been extended to high volume production of passenger cars (0.5 to 1.0 million per unit). Also more than 70% of the FMS installations are for prismatic parts.

Considering the above factors, an FMS for machining prismatic parts like transmission cases, gear boxes, crank-cases, cylinder blocks and cylinder heads of light automotives (cars, LCVs, 2-wheelers, 3-wheelers) is proposed. Excepting cylinder blocks of LCVs, these fall within a 500mm cube. The cylinder block of LCVs is about 500mm x 460mm x 380mm. The cylinder blocks of medium duty vehicles and tractors are about 1 m^3 in size.

Considering the dominant population of light automotives over medium and heavy duty vehicles, it is advisable to go in for an FMS consisting of machining centres, with pallet size 600mm x 600mm, for machining the prismatic parts considered earlier. This is in line with the nation's high priority for transportation, wherein the availability of standard-size automotive parts of high complexity will make it possible to step up production of fuel-efficient light to medium-sized commercial/ transportation vehicles, while improving the productivity of labour, capital and equipment.

Also, this FMS project can cater to the needs of defence production for prismatic parts. A typical hardware configuration proposed for demonstrating FMS concepts is shown in *Fig. 2*.

3.2 Manufacturing Details

Machines

Many FMS installations, existing in other countries for machining similar parts, consist of head-change/head-indexing type machines together with standard machining centres. These machines are more productive compared to standard machining centres as they can carry out multiple drilling, reaming and tapping operations simultaneously. However, they are less flexible. The trend is to use small multiple drilling heads which could be accommodated in the tool magazines of the standard CNC machining centres. So, standard horizontal and vertical machining centres, with pallet size 600mm x 600mm, are recommended. These are readily available in the country and can be connected to a central computer for part program transfer.

Material Handling

About 90% of the FMS installations in Europe and USA are of the rail guided type; wire guided cars and automated guided vehicles are more popular among Japanese manufacturers. Rail-guided vehicles are rigid and reliable with good repeatability, and are immune to disturbances; however, they restrict the plant layout. AGVs use storage batteries, which need periodic recharging and good floor maintenance, but permit a more flexible plant layout. The trend shows that AGVs are becoming more popular, and they are therefore recommended for use in the proposed demonstration project.

Tool Management

An automated tool management system, consisting of a tool presetting device, a tool storage rack, and a tool transfer system by robot-car, for transfer from the tool-rack to the different tool magazines on the machines, is recommended. This takes care of replacing blunt/

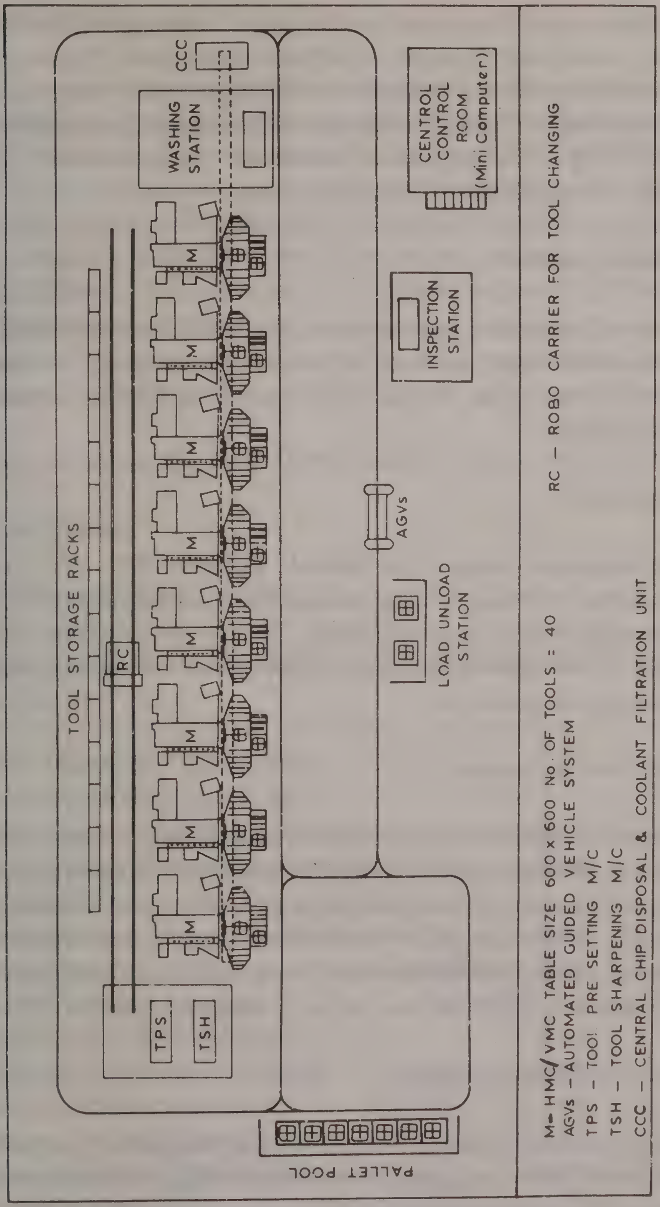
TOOL STORAGE RACKS
RC
TPS
TSH
M
M
M
M
M
M
M
M
WASHING STATION
CCC
CENTROL CONTROL ROOM (Mini Computer)
INSPECTION STATION
AGVs
LOAD UNLOAD STATION
PALLET POOL
M- HMC/VMC TABLE SIZE 600 x 600 No. OF TOOLS : 40
AGVs - AUTOMATED GUIDED VEHICLE SYSTEM
TPS - TOOL PRE SETTING M/C
TSH - TOOL SHARPENINS M/C
CCC - CENTRAL CHIP DISPOSAL & COOLANT FILTRATION UNIT
RC - ROBO CARRIER FOR TOOL CHANGING

Fig. 2 Configuration of the Proposed Flexible Manufacturing System.

broken tools with new tools and the task of changing an entire set of tools on the tool magazine for different components. These operations are carried out while machining is going on. The tool rack should have the capacity to store the entire range of tools required for machining all the components considered. The tool transfer system may be a rail guided or of the gantry type.

Washing Station

After all machining operations are completed, the components are washed thoroughly and rinsed in a washing station before presenting them for inspection. This also helps to clean the locating surfaces of the fixtures.

Inspection

An inspection station is an integral part of a FMS. The values measured regarding size and position of a machined component are compared with the expected values. The corrections, if any, are fed back to the machines so as to get automatic on-line quality control, leading to zero defects.

Supervisory Computer

A mini-computer is recommended as a supervisory computer which coordinates various activities like loading of different part programs to various work centres, movement of pallet carrier between machines, tool transfer, AGV control, scheduling, etc. Several software packages have to be developed for control, coordination and operation of machines, AGVs, robots, and pallet conveyor systems.

Load and Unload Station

The fixtures are prepared and stacked in a pallet pool. Components are loaded on to the fixtures with the help of a gantry loader or a jib crane. With pallets available (40 or more), it should be possible to plan for an unmanned shift during the night.

Workstations

The average machining time for a component may be assumed to be 15 minutes. Assuming 2 shifts and 80% utilisation (which is typical of FMS installations), the number of hours available is 4000/year. Therefore the number of parts machined per year per machine will be 16,000. With a combination of 6 horizontal and two vertical machining centres, it is therefore possible to get an economical volume of 120,000 medium-sized prismatic components per year in 2 shifts, and 180,000 in three shifts.

Cost of the Project

The estimated cost of the FMS Project is Rs 15 crores (see Table 11).

Time Schedule

The time schedule is shown in *Fig. 3*.

Table 11
Cost of the Project

CNC Machining Centres (8 nos) including tooling, spares, etc.	8.00
Minicomputer with all peripherals	0.50
AGV/Robot car/Central chip disposal/ coolant filtration unit	0.50
Tool presetting/Sharpening machines	0.40
Inspection station/washing station/load-unload station with PLC controls	0.60
Tools/Tool racks/Pallet pool	0.50
Building & Factory Equipment	0.50
Software Development Cost	2.00
Salaries/overheads for 3 years	1.50
Materials for trials/proving out, plus miscellaneous	0.50
Total (Rs Crores)	15.00

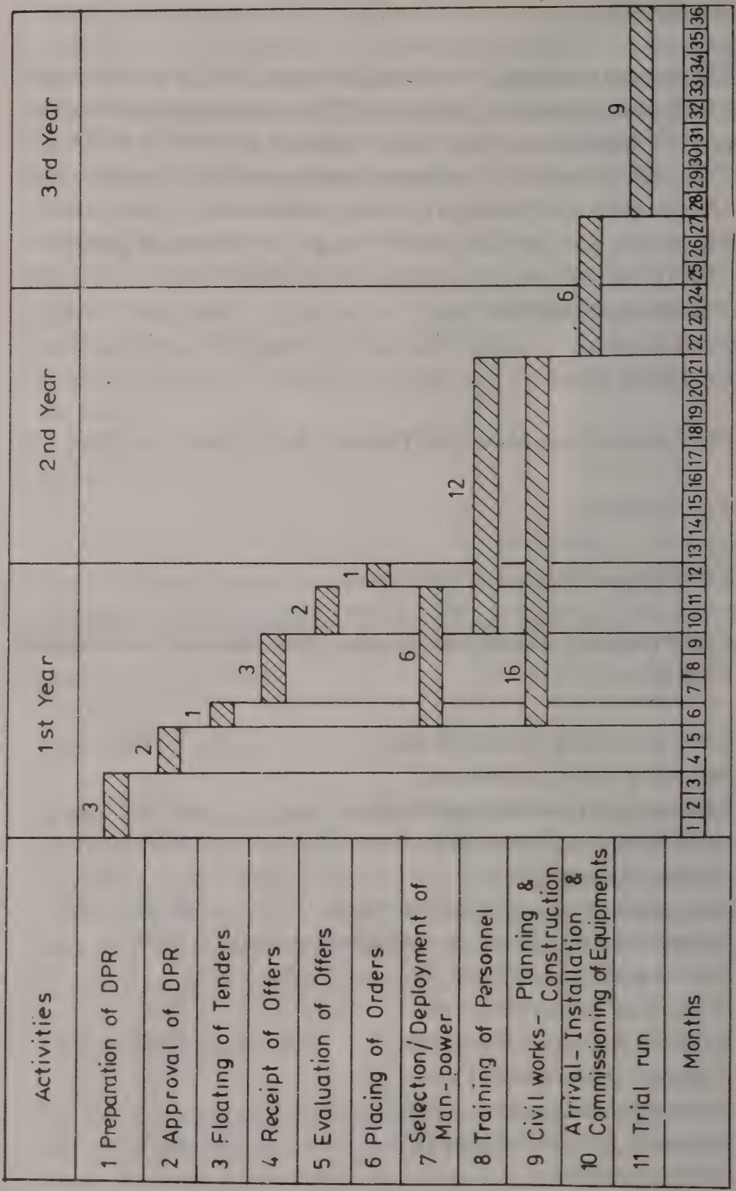

Fig. 3 FMS - Implementation Schedule

4 A Flexible Manufacturing System for Electronics Assembly

4.1 Introduction

Since the early 1970s, the electronics industry throughout the world has assembled billions of components, using automated equipment that can either place or insert components at high speeds while maintaining accuracy and repeatability requirements. With the increasing demand for higher quality, lower cost and higher volume, the electronic assembly industry has to be equipped with surface mounted assembly (SMA) technology having the following features:

- Sophisticated and miniaturised components like chips, surface mounted components, etc.
- Highly automated surface-mounted component pick, place and assembly equipment.
- Robotic assembly equipment instead of manual or semi-automatic assembly of systems.

Automation for electronic assembly of high-volume printed circuit boards would cost anywhere from Rs 10 crores to 40 crores, depending on the variety and batch size of boards. This plant will take already-fabricated PCBs, and several different types of components, for assembly. In order to introduce automation in a phased manner, and to make it available for smaller companies, the machinery is made modular, and compatible with other machines, by using a building block approach. The pick and place machines suitable for small companies will have a maximum output of 3500 to 5000 components per hour, whereas those required for medium to large companies will have an output rate of 5000 to 14000 per hour. Machines of this nature demand precise placement accuracy to accommodate their 50 mil to 20 mil lead/pad spacing.

4.2 Why SMA Technology?

- It saves space (or area; by 35 to 50%) on PCBs and enables a consequent reduction in the size of the end-product.

- The overall PCB assembly cost can come down by 45-50% as compared to assembly by component insertion.
- Electronic assembly can be considerably automated by computer control/programming and the production rates/capacities can be increased by factors of 50 to 100. For the production of digital exchanges, this assumes great significance.
- Flexible production of PCBs is possible to obtain a diverse product mix.
- Quality and reliability of end products will be high, with a rejection of less than 10 parts per million (ppm), converging towards the zero-defect concept.

Table 12

Machines Required for Introducing SMA Technology

SMD (Chip) placement machine.	1
Cylindrical chip component placement machine	1
Axial lead component insertion machine	1
Radial lead component insertion machine	1
DIP IC's automatic insertion machine	1
Square-pin insertion machine	1
Round pin insertion machine	1
Automatic in-line printing machine	1
Adhesive dispensers	2
SOP taping machine	1
Automatic board handling units	5
Solder flow/reflow machines	1
PCB cleaning equipment	1
Host computer for process planning, control of Assembly Machines	1
Microcomputers for business information processing	1
Bare board testers	1
LSI/VLSI tester	1
Discrete active component tester	1
Passive component tester	1
Connector testers	1
Relay testers	1
ATE for assembled cards	2
Cable testers	1
Final product testers	1

Table 12 gives the list of machines required for introducing SMA technology. Depending on the production capacity, and the variety of PCBs, the number of machines will vary. Typically, a high volume facility capable of producing 1000 cards per hour will cost about Rs 20 crores. An example of a suitable flexible manufacturing line layout is shown in *Figs. 4 and 5.*

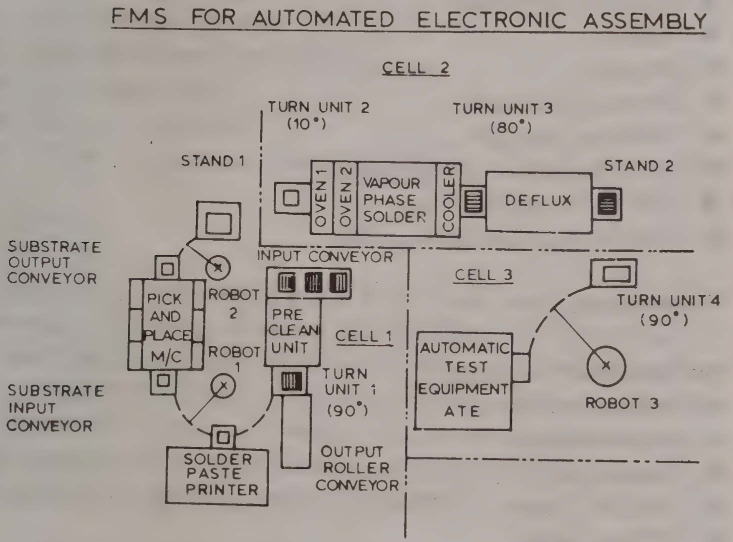

Fig. 4 Manufacturing line layout.

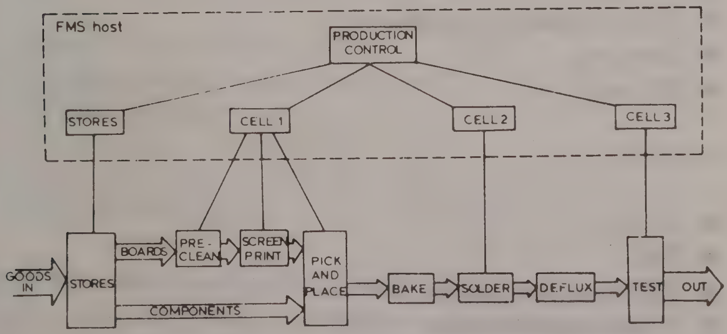

Fig. 5 Manufacturing line co-ordination sub-system.

Telecommunication Products Amenable to SMA:

Terminal Equipment

- Phone (electronic)
- Teleprinters
- FAX terminals
- Data entry terminals
- Printers
- Displays
- Personal computers
- Voice response unit
- Recording devices (voice, video)
- Text processing terminals
- Distributed processing terminals

Transmission

- Wire cable electronics
- Micro wave systems
- Broadcast radio
- Broadcast TV
- Satellite systems
- Cellular mobile
- Cellular microwave
- Analog/digital multiplexers
- Modems
- Line conditioning equipment
- Antennas
- Repeaters

Switching

- Key sets
- PABX
- Private tandem switches
- Central office switches

- Electronic mail switches
- Voice mail switch
- Remote switch
- Cellular mobile switches
- Automatic call distribution (ACD)
- Packet nodes
- S/F message switches
- Protocol concentrators
- Data concentrator/multiplexer
- Line concentrator
- Data PABX (LAN)
- Digital access control system (DACS)

Implementation

Automation for electronic products is mainly available for PCB assembly and testing. However, such a facility is not yet used in the country because it is not economically viable with our small volumes of production for a large product mix. In select areas of consumer/ communication electronics, however, it is possible to introduce SMA automation and reap the benefits of reduced cost, increased quality/ reliability, and greatly improved productivity.

As very little automation and computerisation is practised in the electronics industry in India, the first phase would be to integrate all the business information on the computer using

- Material resource planning (MRP)
- Production planning/co-ordination (PPC)
- Sales management
- Auto quotation
- Stores management
- Financial management

The Second phase would be to integrate the various processes through computer communications in controlling and monitoring the manufacturing activities such as assembly, testing and quality assurnace.

5 Establishment of R & D Centres

5.1 A Centre for Computer Integrated Manufacturing at Heavy Alloy Penetrator Project, Trichy

5.1a Introduction

The HAP Project, under the Ministry of Defence at Trichy, has been set up to manufacture precision components for ordnance applications from exotic alloys, using advanced manufacturing technology in the areas of metallurgy, machining and surface treatment. To meet the objective of the manufacture of high quality defence products in this new factory, a major production unit with a high degree of automation is coming up at Trichy.

5.1b Existing Facilities

Facilities installed for the machine shop include the following:

- 22 CNC turning machines with programming capabilities, integrated with automatic tool changers, tool and part probes, for in-process gauging, and an integrated electronic workpiece measuring system for automatic tool correction.

- Automatic workpiece loading/unloading, gantry system (robot) integrated with pallet stacks.

- Automated guided vehicles, with on-board microcomputer, working under the supervision of a central stationary computer (PDP 11/73), to carry out the material and tool handling among the various work centres.

- Electronic gauging with data acquisition and on-line statistical analysis to carry out 100% inspection.

- A supervisory computer interfaced to all the machines/equipment to provide graphical representation of the shop floor status like production, inspection, equipment downtime etc. on a real time basis.

Further, the system is interfaced to a PC/AT to generate periodic production and inspection reports.

5.1c - Future Plans

HAPP is committed to implementing its computer integrated manufacturing programme by 1991. The major production unit (machine shop) based on the CIM concept will be operational from early 1989. It is planned to extend the CIM concept progressively to other manufacturing shops, including assembly, installing robots, computerised shop floor data collection systems, bar code/vision systems for product identification and tracking. In association with other agencies, expert systems in areas such as maintenance, production planning, materials and quality management are also being developed.

Research and development, carried out in close cooperation with manufacturing units such as HAPP, will provide practical and useful information on the effectiveness of, and problems associated with, CIM. Some of the key areas proposed to be taken up during the next two years for progressive implementation of CIM will be the following:

- Vision and other non-contact gauging systems, wherever multipoint electronic gauging units are not feasible.

- Bar code, voice recognition and image scanning systems for auto identification of components/materials and instantaneous data entry.

- Lasers for precision measurements and calibrations/inspections of CNC systems and other applications in manufacturing.

- 3D CAD (solid modelling) software interfaced with group technology and computer aided process planning software to facilitate future design modifications (if any), and for automatic generation of bills of materials, process sheets and the operation sequence (material routing).

- PC based software in the areas of statistical quality control/

statistical process control (SQC/SPC), facilities planning, simulation of factory operations, time and motion studies, critical resource management, decision support and other management information systems (MIS) related tasks with a scientific and quantitative approach.

- Interfacing of all machines/equipment with shop level and plant level computers for integrated on line performance tracking and control, through suitable communication such as manufacturing automation protocol/technical office automation protocol (MAP/TOP).

- Expert and knowledge-based systems in technology- intensive areas such as CNC machine diagnostics.

5.1d Centre for CIM

In view of the above it is proposed that a centre on computer integrated manufacturing be set up at HAPP, Trichy, contiguous to the present factory in the area already earmarked for R & D.

An investment of Rs.7 crores on the centre is recommended, and will be utilized as follows:

- Building and support facilities : Rs. 1 crore
- Equipment and related facilities: Rs. 6 crores

The Centre should be a cooperative effort of the Ministry of Defence, Department of Science and Technology and the Ministry of Industry, and governed by a high level governing council constituted with representatives drawn from Defence Production, Defence R & D, DST, HMT and academic institutions.

The major functions of this centre will be to

- work closely with HAPP, giving full support for progressive implementation of CIM

- assess performance of CIM implementation at HAPP and consider modifications for further improvement

- keep track of developments in automation and computer applications in manufacturing, set up a prototype, evaluate performance for use in industries

- develop models for evaluating productivity and cost effectiveness of CIM factories in the Indian environment

- acquire, develop, modify and improve upon the avialble computer based manufacturing management software

- interact with hardware and software agencies to develop components and sub-systems for factory automation; and,

- provide technological support for implementation of CIM both in existing and in new automated factories in the country.

5.2 Manpower Training and R&D

If CIM is a strategy for the new industrial revolution, and is indeed the wave of the future, there is an urgent need to orient industry, R & D laboratories and academic institutions to initiate CIM programmes in research, development and training. The following specific recommendations are made.

- R & D programmes should be initiated to absorb foreign technology available in the area of automation products development. Such products include advanced machine tools, material handling equipment, industrial robots, advanced computer systems, and data acquisition equipment including sensors and actuators.

These programmes should be initiated in selected private and public sector industries under a supervising Government agency. This agency would be responsible for creating and maintaining a database on Indian and foreign automation products, should guide the absorption of foreign technology, and should provide ideas for innovation.

- A centre for software development should be set up in consultation with DoE. It should undertake development of programmable logic controllers, hierarchial control software, local area networks, protocols, software for planning, configuring and scheduling, expert systems for various levels of decision making, and business software such as MRP-II and JIT. The development of such software requires skilled manpower and can provide a challenge to young minds. The structure of this centre should allow sub-contracting the development to smaller firms, and funding projects in educational institutions.

- CIM is a philosophy of treating all 'business' functions in an integrated way : design, manufacture, testing and marketing. These functions are traditionally treated in isolation. The multiplier effect on productivity of this integration is what makes CIM extremely attractive. There is an urgent need to spread the CIM culture among our existing workforce and also to train future engineers/managers in CIM. If the factories of the future are to be run by software, with workers directing and using their minds rather than hands, we need front-line managers who can exercise more and more decision making authority. We need plans to create such young people. Our suggestions include:

    ○ Setting up of centres of excellence at IISc, the IITs, the IIMs and other selected universities for undertaking basic research, software development, equipment designs, consultancy projects and organising continuing education and BE/ME courses. In a very broad sense, CIM courses in BE/ME can be organised under the existing set ups by introducing computer-aided design, manufacturing engineering, testing and management courses. This, however, requires computer resources as well as teachers trained/retrained in these disciplines. Computerisation of all relevant engineering courses, and an emphasis on a well organised integrated business enterprise in all educational institutions, would pave the way for spreading the CIM culture and developing curricula in all universities and colleges.

○ Organising conferences/workshops/seminars on these topics at various levels, for both senior and working engineers.

5.3 Studies on the Social Effects of Automation

Automation has often been viewed with some suspicion by labour around the world. Labour acceptance of automation is vital for its introduction in a factory environment. The main fear seems to be loss of jobs. This is an important issue that needs serious consideration.

Experience from elsewhere in the world clearly indicates that automation will improve the general economic well-being and labour productivity; it does transfer jobs from manufacturing to the service sector but it does not cause unemployment provided its introduction is carefully planned. In fact, a country such as Japan, which has a population density far exceeding ours, has no unemployment problem although it has the greatest number of automated plants both in numbers and in sophistication. Advanced technology, in every country, has contributed to fuller employment and better wages.

If our country holds back on the introduction of manufacturing automation in a misguided effort to preserve jobs, the net loss of production, combined with low quality and high cost, would, in the end, result in sick factories, thus destroying far more jobs than the introduction of automation would throw up. The real problem of employment is that, because of shortage of capital, we are not able to invest enough to provide employment to our rising population; but surely this does not mean that we should resign ourselves to low technology, low productivity and low wages (which would result in production of shoddy goods that cannot be sold in the markets, indirectly encouraging brain drain and smuggling). The prime purpose of manufacturing industries is to produce goods that sell. In these days of internationalised manufacturing, the issue is not whether one *wants* to automate or not but whether the competitor *has* automated or not.

Despite the above argument, unemployment is an issue that is to be approached with sympathy and careful planning. Research work should be initiated to investigate issues such as training and retraining programmes for skilled and middle managerial staff, alternative employment schemes for displaced labour in various sectors etc.

6 Conclusions

In this report, we have endeavoured to bring out the importance of automated manufacturing to our country and suggested several strategies to harness its potential. We realise that the implementation of projects involving automation will face a variety of difficult problems. Still such projects have to progress, and carry along everyone concerned.

To spread the culture of automated manufacturing, and to develop expertise in the area, we have suggested several measures including the establishment of pilot plants and the creation of R & D centres, and a central agency that would be responsible for overall direction of programmes.

We realise that manufacturing encompasses several fields involving thousands of components, assemblies and products. We are also aware that there exist public and private sector factories, built with investments of the order of thousands of crores of rupees, specifically for manufacturing. It should be an objective of government policy to upgrade the inefficient ones among these factories, phase out the unprofitable ones, and, at the same time, start new factories to manufacture selected products.

Task forces should be set up in sectors such as electronics, metal cutting and electrical appliances, charged with the task of formulating action plans for improving quality and reducing cost.

It is our conviction that the CIM approach to manufacturing, advocated in this document, would usher in factories with greater productivity and quality and improve the general well-being of the country's population.

7 Summary of Recommendations

Productivity and quality are central to industrial growth. In most successfully industrialised nations, computer integrated manufacturing (CIM), involving the use of information technology, has been demonstrated to be a key strategy to achieve, at once, high quality of product, enhanced productivity, and resilience and competitiveness in uncertain global markets. CIM is the wave of the future in production technology. Several countries, both developed and developing, have invested billions of dollars in education, research and technology development in CIM; and many of the nearly 600 factories set up in the world utilising the new technology have proved profitable.

Manufacturing is an increasingly important wealth-creating and employment-generating segment of the Indian economy. However, our products are by and large not competitive in either domestic or world markets because of high cost and low quality. Our factories depend largely on imported technologies that are at least a decade old, and suffer from low labour productivity; many factories do not run as competitive business enterprises and create little wealth for the country.

The Working Group considers it feasible to nurture competitive manufacturing by harnessing the potential of information technology in the manufacturing sector.

The following are the major recommendations:

- *Launching a National Programme in Robotics and Manufacturing Automation (RMA).*

A central coordinating agency to be called the National Agency for RMA (NARMA) should be created to identify products/factories that need computer-aided technologies in the manufacturing sector, and to draw action plans to

- spread the culture of RMA and quality consciousness among all concerned,
- promote blue collar acceptance of, and white collar commitment to, RMA,
- develop retrofitting strategies to upgrade current technology and management techniques in our factories,
- conduct systems-engineering studies for streamlining and modernisation of operations in the identified factories,
- initiate R&D work for developing CIM technologies and techniques indigenously,
- train and retrain manpower, and
- start new factories in vital areas.

Important products for such new factories include: electrical motors, TV tubes, electronic exchanges, two-wheelers, bicycles and prefabricated house equipment.

- *Government Support and Subsidies*

Setting up such high-tech manufacturing plants, or retrofitting old plants, and the associated manpower retraining, entails huge capital costs. To pursuade the industry to harness the potential of CIM, it is therefore necessary to provide free consulting services to the first few installations, low interest loans, tax concessions or subsidies on related capital investments, customs duty exemption on essential components/ subsystems, and liberalised import policies.

- *Manufacture of Automation Products*

Automation products for setting up modern, fully or semi-automated factories include such subsystems as: factory floor equipment (CNC machine tools, robots, automated guided vehicles and other material-handling equipment); computer hardware (programmable controllers, local area networks, computer-aided design workstations); software products (computer-aided process planning, material requirements planning (MRP), total quality control (TQC), expert systems for scheduling, planning and configuring manufacturing facilities); and finally, sensors and actuators (bar-code readers, vision sensors, tactile sensors, motors, etc.).

These technologies or products are already becoming sensitive; it is therefore essential to have well defined policies to manufacture them in the country, through selective collaboration with reliable vendors and indigenous development. In many software products we should have an export potential as well, and it is necessary to exploit such potential.

- *Education and R&D*

Indigenous R&D is vital to absorb and upgrade foreign technologies, and to maintain our manufacturing potential. The following R&D programmes therefore need to be initiated: cutting tool technologies and machine tools based on them; new material-handling equipment; methods of planning, designing, and operating advanced manufacturing systems; economic analysis; software development; expert system development; computer control system design methods with fault-tolerant features; new management techniques; and the study of human factors and social effects of automation.

We recommend that R&D centres and special interest cells be created in reputed academic and R&D institutions under the Ministry of Human Resources Development, UGC and CSIR, to promote the above R&D programmes. We also recommend the setting up of an R&D Centre for CIM at the Heavy Alloy Penetrator Project (HAPP), Trichy, contiguous to the present factory.

On the education front, it is essential to upgrade engineering curricula in the country to include courses on computer aided design and management, automation, robotics and manufacturing. Well planned educational programmes should be conducted to upgrade the knowledge of practising engineers, designers and educators in factories, consulting firms and universities.

- *Pilot Projects*

Three demonstration projects should be set up for the dual purpose of developing expertise in RMA project implementation and of serving immediate industrial needs for certain components. These include

- Automation and robotics for nuclear power plants,
- A flexible manufacturing system for prismatic components, and
- A flexible manufacturing system for electronic assembly.

It is our conviction that the CIM approach to manufacturing would lead to

- meeting certain special needs in sensitive areas such as defence and nuclear applications,
- production of export goods of internationally acceptable quality at competitive prices,
- meeting the needs of the domestic market without making it protectionist, and
- production of high quality consumer goods at low cost while conserving natural resources and energy, at the same time contributing to the employment potential.

Annexures

Annexure-1

Composition and Terms of Reference of Science Advisory Council to the Prime Minister*

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Terms of Reference

The Council will advise the Prime Minister on:

- Major issues facing Science and Technology today
- The health of Science and Technology in the country and the direction in which it should move and
- A perspective plan for A D 2001.

The Council will also look at specific problems with different scientific departments, policies, priorities for research and technology missions, etc.

Annexure-2

Composition of Sub-Committees Set Up to Prepare the Technical Reports

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